NASA/TM–2002-211841

Neurolab

Final Report for the Ames Research Center Payload

A. Christopher Maese, Louis H. Ostrach, Editors

October 2002

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Acknowledgments

An undertaking to document activities and experiences years after the fact is a difficult task, especially when individuals have moved on to different careers and those that remain are involved in other flight opportunities. Faced with this challenge, the individuals from Mains Associates, specifically, Scarlett Chidgey, Sharon Reynolds, Richard Mains, and Greg Leonard should receive recognition for their contribution in helping to create this document.

Considering the decrease in funding to authorize the resources required to document ARC's contribution to the NL mission, James Connolly and Bonnie Dalton had the foresight to realize its usefulness as we commit ourselves to the next generation of space flight activities on the International Space Station.

This report documents the critical activities and experiences of many individuals at NASA Ames Research Center. While it would be impossible to name every individual, special recongition should be given to the following who contributed to the document: James Connolly, Paula Dumars, Mark Flynn, Justine Grove, Cindy Havens, Anthony Intravaia, Jennifer Kwong, BJ Navarro, Shahn Spratt, Marianne Steele, Marilyn Vasquez, and Angela Wray.

A list of groups at the center and investigator affiliations who contributed to the ARC portion of this mission is warranted:

Bionetics Corporation
Hernandez Engineering, Inc.
Lockheed Martin Engineering and Sciences
MICRO CRAFT. Inc.
NSI Technology Services Corp.
Simco Electronics
Sterling CCR
Sverdrup Technology
Brooklyn College, New York
C.E.B.A.S Center of Excellence Rurh-University, Germany
Fukushima Medical College, Japan
Harvard Medical School, LMRC Brigham & Women's Hospital
Medical College of Wisconsin, Milwaukee
New York University Medical Center, New York
Universite de Montpellier II, France
University of Arizona, Tuscon
University of California, Davis
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University of medicine and Dentistry Robert Wood Johnson Medical School, New Jersey
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Preface

A mission patch...a STS flight number...names of the astronauts. These are generally some of the impressions that remain after a space flight mission. For the scientists that had investigations conducted onboard, their involvement leads to future ground and flight studies that generate new information and more challenging questions. But little is remembered of the different people and disciplines that must collaborate as a team to accomplish the mission. Between the concept in the minds of NASA upper management and implementation by a team of dedicated individuals lies the real work that leads to the success of a space flight mission.

Flying animal research subjects provides its own unique challenges, including optimization of their health and welfare as well as ensuring that procedures involved in their care and use do not negatively impact the humans who coexist in the same environment. This is possibly the greatest challenge in non-human, space life science research, and it influences the design of hardware as well as onboard operations. But with every flight comes new learning that brings us closer to understanding our potential and limitations.

The purpose of this publication is to document NASA Ames Research Center's involvement in the last Spacelab mission (STS-90, Neurolab) to be flown. It is not intended to profile the details encountered in four years of involvement, but to provide a summary record of the different disciplines required to come together at ARC to develop and implement this mission. The focus is primarily on the science component of the mission, but also includes the major operations and engineering aspects. Where possible, lessons learned or more appropriately, recommendations, are written to provide insight into planning for future life sciences payload projects on Space Shuttle and International Space Station. These recommendations, of course, cannot address all facets of payload development and implementation. Future space flight missions will continue to rely on dedicated individuals who have participated in space flights and who share their previous experiences to avoid the obstacles and meet the challenges that will undoubtedly be encountered.

I had the greatest privilege in working with a team of dynamic individuals—each contributing to the best of their abilities and deeply committed to working in the space program. Without people of this caliber, we could not have accomplished what we set out to do.

A. Christopher Maese
Neurolab Payload Manager

Nomenclature

Acronyms

AWA	Animal Walking Apparatus
AT	Aquatic Team
AGC	Asynchronous Ground Control
AEM	Animal Enclosure Module
AO	Announcement of Opportunity
ARC	Ames Research Center
CEBAS	Closed Equilibrated Biological Aquatic System
CSA	Canadian Space Agency
CTS	circadian timing system
CNS	central nervous system
COTS	Commercial off-the-shelf
CRISP	Crickets in Space
DAP	Data Archiving Project
DARA	Deutsche Agentur für Raumfahrt-Angelegenheiten
DBP	Diagnostic Blood Pressure
DFRC	Dryden Flight Research Center
DIU	Data Interface Unit
DLR	DeutscheForschung-sanstalt für Luft-und Raumfahrt (German space agency)
DR	Data Recorder
DSTI	Discrete to Serial Interface Unit
EDAS	Electronic Data Analysis System
ECDS	Electronic Data Collection System
ECG	electrocardiogram
EDL	extensor digitorum longus
EPSP	Experiment Power Switching Panel
EVT	Experiment Verification Test
FD	flight day
FLT	Flight
FP	Fish Package
FPCU	Fish Package Control Unit
FRA	Fos-Related Antigens
GPWS	General Purpose Work Station
HQ	NASA Headquarters
HD	head direction
HR	heart rate
HFRB	Hardware Failure Review Board
IANA	Integrated Aortic Nerve Activity
IEG	immediate early gene
IO	Inferior Olive
INP	Integrated Neuronal Plasticity
JSC	Johnson Space Center
KSC	Kennedy Space Center
L+	Launch day plus
LC	Locus Coerulus

LD	Light/Dark cycle
LIRD	Logistics Integrated Requirements Document
LL	Light/Light cycle
LM	Lab Module
LRt	Lateral Reticular
μG	microgravity
μm	micrometer
MBP	mean blood pressure
MD	Mammalian Development
MMO	Mission Management Office
MIT	Mission Integrated Training
Mve	Medial Vestibular
MITS	Mission Integrated Training Simulations
Mrna	messenger Ribonucleic Acid
MWM	Morris water maze
MHC	myosin heavy chain
MD	Mammalian Development
NASDA	National Space Development Agency of Japan
NB	Neurobiology
NDAS	Neural Data Acquisition System
Neurolab	NL
NBC	Neurolab Biotelemetry Chassis
NBS	Neurolab Biotelemetry System
NIH	National Institutes of Health
NP	Neuronal Plasticity
NRA	NASA Research Announcement
NST	Nucleus of the Solitary Track
O&C	Operations and Checkout
OES	Orbiter Environmental Simulator
OFA	open field apparatus
PB	Phosphate Buffer
PBS	Phosphate Buffer Solution
PE	Phenylephrine
PED	Payload Element Developer
PI	Principal Investigator
PN	post-natal
POCC	Payload Operations Control Center
PSRP	Payload Safety Review Panel
PSI	position sensitive interneuron
R+	Recover day plus
RAHF	Research Animal Holding Facility
RAM	radial arm haze
rCHR	roll-induced compensatory head response
RSO	Radiation Safety Officer
Rx	Receiver
SBP	systolic blood pressure
SCN	suprachiasmatic nucleus
SD	standard deviation
SIM	Simulated Caged Control
SL	ARC Life Sciences Division
SPF	Specific Pathogen Free

SPAF	Single Pass Auxiliary Fan
SpVe	Spinal Vestibular
TMA	Test Monitoring Area
T3	thyroid hormone
TD	thyroid deficient
TDPU	Telemetry Data Processing Unit
TOP	Test Operation Procedures
Tx	Transmitter
VFEU	Vestibular Function Experiment Unit
VIV	Vivarium

1.0 Overview

1.1 Introduction

This report provides an overview of the Ames Research Center (ARC) payload on the Neurolab mission with a brief overall mission description, followed by the ARC payload description. The Science section includes science-related project data and profiles of each experiment with results, as available at the time of this publication. Each flight hardware element developed to support the ARC payload is described in the Hardware section. Payload Operations includes payload preparation and preflight, inflight, and postflight operations.

It is also the intention of this report to collect and share the major lessons learned from Neurolab. The lessons-learned have been described in two parts, whenever possible. First, the observation or anomaly (for hardware) is provided and second, the lesson-learned is described with the proposed change that could likely avoid repetition of the problem or minimize the associated risk. The sources for these include: a) interviews conducted with several key ARC Neurolab personnel; b) an internal report prepared recently by the Life Sciences Division which collected lessons learned from various mission-related reports and publications; and c) from "Lessons from Neurolab," a published report by NASA management (reference #4 in the References & Related readings section).

It is unlikely there will be agreement by NASA and contractor staff on all the lessons learned. However, the NASA ARC Neurolab team feels a major obligation to its former members and future payload teams to document those frequently mentioned. Much has been learned during the Shuttle era on how to conduct increasingly sophisticated life sciences research in space, and even more will be learned on the continuously orbiting International Space Station.

1.2 Background

The Neurolab mission flew on STS-90, which launched on the Space Shuttle Columbia from Kennedy Space Center (KSC) on April 17, 1998. There were seven crewmembers, including one astronaut from the National Space Development Agency (NASDA) of Japan and one from the Canadian Space Agency (CSA). The 16-day mission ended May 3, with a landing at KSC.

Neurolab, the final Spacelab mission, was dedicated to studying the nervous system. In 1990, the U.S. Congress passed a joint resolution to designate the 1990s the "Decade of the Brain" to enhance public awareness of the benefits to be derived from brain research. The resolution authorized and requested the President to issue a proclamation in observance of this occasion, in which he called upon public officials and citizens to observe that decade with appropriate programs, ceremonies, and activities. In 1992, NASA proposed the Neurolab mission as a contribution to this mandate.

To further define the Neurolab mission, NASA held a series of seven Science Working Groups to identify important areas of neuroscience and behavior research for space. NASA also contacted U.S. government agencies and international space agencies and proposed they collaborate on the mission. In July 1993, NASA released an Announcement of Opportunity (AO) to solicit proposals, and received 172 in response.

The Neurolab mission goals were to:

- Determine the effects of microgravity on human and animal subjects on the same mission
- Advance scientific knowledge about the brain and the nervous system
- Use the unique environment of space flight to study fundamental neurobiological processes
- Increase understanding of the mechanisms responsible for neurobiological and behavioral changes that occur in space flight
- Further life sciences goals in support of human space flight
- Apply results from space studies to the health, well-being, and economic benefit of people on Earth
- Use Neurolab as a model for international and interagency cooperation in space flight research

The mission was conducted as a cooperative effort between NASA and various domestic and international partners. Domestic partners included several NIH institutes (Division of Research Grants, National Institute of Aging, National Institute of Deafness and Other Communication Disorders, National Institute of Neurological Disorders and Stroke, National Heart, Lung, and Blood Institute), the National Science Foundation, and the Office of Naval Research. International partners included the Canadian, European, French, German, and Japanese space agencies.

A Steering Committee composed of members representing each collaborating entity provided overall mission management guidance and scientific direction for Neurolab. The NIH Division of Research Grants provided the scientific expertise for generating independent peer reviews of the proposed Neurolab experiments to help NASA and the Steering Committee select a high-quality complementary set of experiments for the mission. Domestic partners also provided funding for the ground-based portion of those proposals that required such studies. The German space agency, DARA, (which has since become DLR), and the Japanese space agency, NASDA, provided hardware and supported experiments for the ARC-managed Neurolab payload complement.

Neurolab was managed by Johnson Space Center (JSC) and its Life Sciences Directorate Mission Management Office (MMO). The mission was composed of two Payload Element Developers (PEDs): Ames Research Center (ARC), responsible for the animal experiments; and JSC, responsible for the human experiments. Both ARC and JSC Project Offices performed an engineering, cost, and management evaluation of Neurolab experiments from December 1993 to March 1994. This evaluation, together with the peer reviewed scores, was used to select the complement of Neurolab experiments. ARC and JSC then became actively involved in assisting investigators to scope experiments to stay within the resources allocated and to initiate reassessments of the resources required. A mission accommodation assessment of the Neurolab payload was conducted by MMO. Figure 1.1 shows the ARC payload organization.

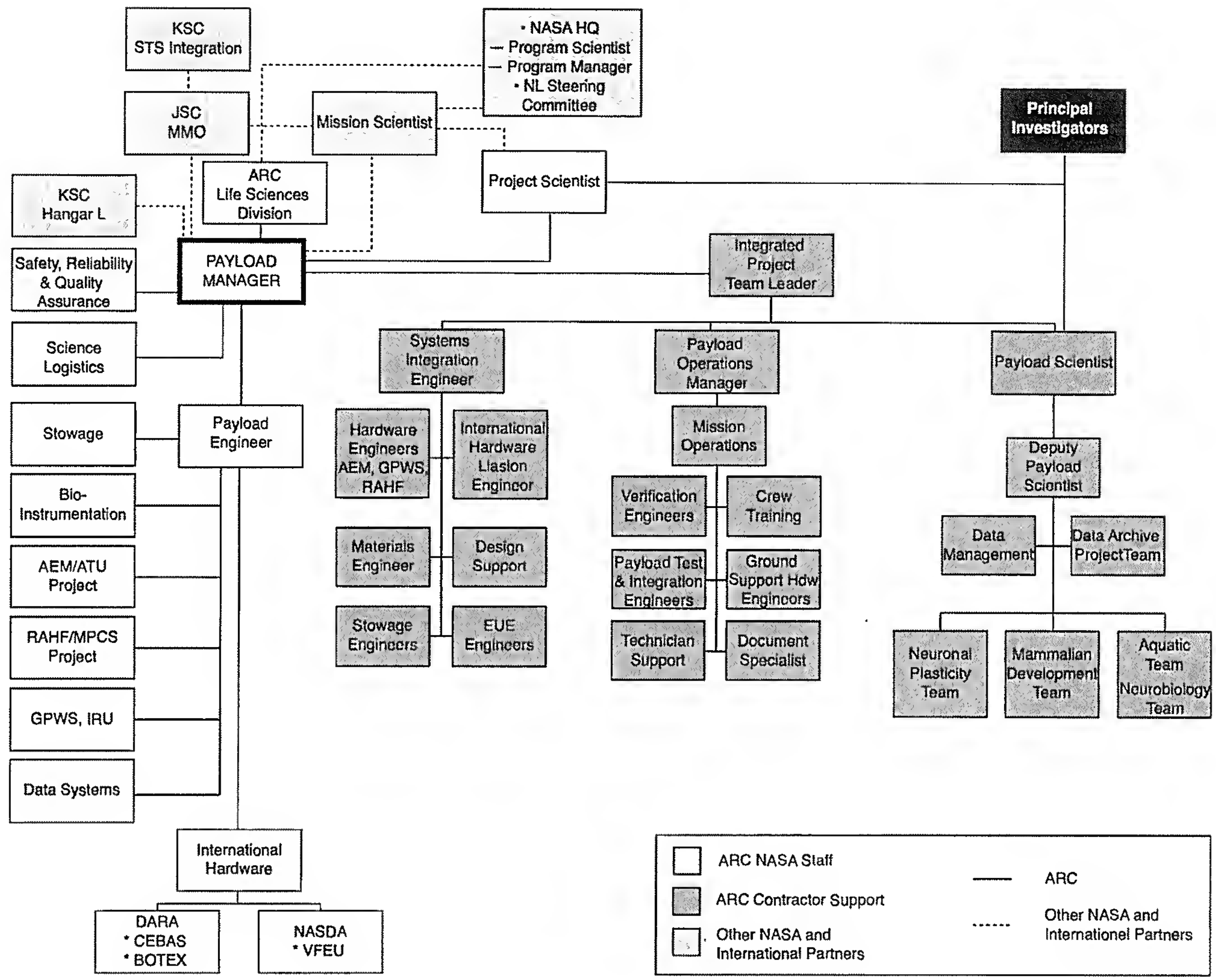

Figure 1.1 ARC Neurolab Payload Development Organization

1.3 Ames Research Center Payload Overview

The primary objective of the ARC payload was to study the adaptation and development of the nervous system in altered gravity fields. The 15 experiments accepted for development and sponsored by ARC were grouped into four science discipline teams: Neuronal Plasticity (five experiments), Mammalian Development (seven experiments), Aquatic (two experiments), and Neurobiology (one experiment).

Specimens onboard at launch included 170 rodents (adult and neonatal rats, mice); 4 oyster toadfish; 204 swordtail fish (4 adult, 200 neonates); 60 water snails and 75 snail egg packets; 824 larval crickets and 690 cricket eggs; and 50 grams hornweed aquatic plants (primarily used to produce oxygen for the swordtail fish and snails). Table 1.1 lists the title, the Principal Investigator, specimens, and habitats flown for each experiment in the ARC payload.

Table 1.1. ARC Experiments, Principal Investigators, Subjects, and Habitats

Team/Experiment	Animal Subject	Habitat
Neuronal Plasticity		
CNS Control of Rhythms and Homeostasis during Space Flight PI: *Charles A. Fuller*	Adult Fischer 344 male rats (*Rattus norvegicus*)	Research Animal Holding Facility
Anatomical Studies of Central Vestibular Adaptation PI: *Gay R. Holstein*	Adult Fischer 344 male rats (*Rattus norvegicus*)	Research Animal Holding Facility
Ensemble Neural Recording of Place Cells in Rats during Space Flight PI: *Bruce L. McNaughton*	Adult Fischer 344 male rats (*Rattus norvegicus*)	Animal Enclosure Module
Effects of Microgravity on Gene Expression in the Brain PI: *Ottavio Pompeiano*	Adult Fischer 344 male rats (*Rattus norvegicus*)	Research Animal Holding Facility
Multidisciplinary Studies of Neural Plasticity in Space PI: *Muriel D. Ross*	Adult Fischer 344 male rats (*Rattus norvegicus*)	Research Animal Holding Facility
Mammalian Development		
Neural-Thyroid Interaction on Skeletal Isomyosin Expression PI: *Kenneth M. Baldwin*	Rat dams & neonates (*Rattus norvegicus*)	Research Animal Holding Facility
Neuronal Development under Conditions of Space Flight PI: *Kenneth S. Kosik*	Rat dams & neonates (*Rattus norvegicus*)	Research Animal Holding Facility
Reduced Gravity Effects in the Developing Nervous System PI: *Richard S. Nowakowski*	Pregnant mice (*Mus musculus*)	Animal Enclosure Module
Microgravity and Development of Vestibular Circuits PI: *Jacqueline Raymond*	Rat dams & neonates (*Rattus norvegicus*)	Research Animal Holding Facility
Effects of Microgravity on Neuromuscular Development PI: *Danny A. Riley*	Rat dams & neonates (*Rattus norvegicus*)	Research Animal Holding Facility
Postnatal Development of Aortic Nerves in Space PI: *Tsuyoshi Shimizu*	Rat dams & neonates (*Rattus norvegicus*)	Research Animal Holding Facility
Effects of Gravity of Postnatal Motor Development PI: *Kerry D. Walton*	Rat dams & neonates (*Rattus norvegicus*)	Animal Enclosure Module Research Animal Holding Facility

Table 1.1, continued. ARC Experiments, Principal Investigators, Subjects, and Habitats

Team/Experiment	Animal Subject	Habitat
Aquatic		
Chronic Recording of Otolith Nerves in Microgravity PI: *Stephen M. Highstein*	Toadfish (*Opsanus tau*)	Closed Equilibrated Biological Aquatic System
Development of Vestibular Organs in Microgravity PI: *Michael L. Wiederhold*	Pond snail (*Biomphalaria glabrata*) Swordtail fish (*Xiphophorus helleri*) Hornweed (Aquatic Plants) (*Ceratophylum demersum*)	Vestibular Function Experiment Unit
Neurobiology		
Development of an Insect Gravity Sensory System in Space PI: *Eberhard R. Horn*	Crickets (*Acheta domesticus*)	BOTEX Incubator

Hardware flown on Neurolab to support the ARC payload included habitats, experiment unique equipment (EUE), support hardware, and stowage. Habitats included the Animal Enclosure Module (AEM), BOTEX Incubator, Closed Equilibrated Biological Aquatic System (CEBAS), Research Animal Holding Facility (RAHF), and the Vestibular Function Experiment Unit (VFEU). Experiment specific hardware was developed and flown to test rodents (E100 and E150) and record biotelemetry data (Neurolab Biotelemetry System) inflight. The General Purpose Work Station (GPWS), Microinjection Kit, Perfusion Warmer Bag Assembly, and many additional kits and miscellaneous stowage items supported conduct of various inflight procedures. ARC stowed hardware consisted of a total of 231 unique items (489 pieces total provided by ARC, MMO, DLR, and NASDA). Attachment 2 provides a list of stowage items. Configurations of the Neurolab hardware (including stowage) in the Spacelab and Middeck are shown in Figures 1.2, 1.3 and 1.4.

Hardware developed by international partners included two items developed by DLR, the BOTEX (previously flown on the German Spacelab mission D-2, in 1993) and the CEBAS (flown previously on STS-89/CEBAS); and the VFEU, developed by NASDA (previously flown on STS-47/SL-J and STS-65/IML-2).

1.3.1 Payload Definition

Definition of the ARC payload began with the 82 proposals received for non-human experiments. In 1994, ARC performed technical evaluations of the proposals for NASA Headquarters (HQ). The Steering Committee reviewed the technical assessments and accepted 19 ARC proposals for definition, which entailed detailed definition of experiment requirements and feasibility. To integrate the science and optimize use of mission resources, HQ established four science discipline teams; each team was to develop an integrated proposal. Early in 1995, ARC, JSC Mission Science, and HQ held meetings to review the integrated proposals. ARC and KSC met to discuss launch site requirements and payload support feasibility. NIH Division of Research Grants conducted reviews of the integrated proposals while the Steering Committee reviewed options for accommodation. In June of 1995, 15 experiments were selected for development.

The NASA HQ payload development goal for the Neurolab mission was to use existing hardware. At the start of the Neurolab Definition process, ARC and its international partners operated under the following HQ guidelines: 1) Existing rack mounted hardware would be

reflown with minor modifications; 2) Experiment Unique Equipment hardware developed for use on SLS-2 as well as commercial-off-the-shelf items would be utilized wherever possible; 3) Experiments would be integrated to maximize scientific returns. The one hardware exception to guideline #1 was the RAHF, where it was known at the outset that major hardware refurbishment would be required.

The assumption that previously flown hardware could be taken out of inventory and reflown with minimal effort turned out to be only partially valid. As the science was more fully defined, and in some cases, verified with existing rack-mounted or experiment unique hardware, it became apparent that hardware modifications would be necessary, thus invalidating ARC's initial budget estimates. HQ decided that once the experiments were selected, every effort would be expended to support those experiments. During further experiment definition, some experiments were determined to be high technical risks. Due to the large number of hardware elements flown, the combined risks became of even more significance to the baseline budget and schedule. NASA's early commitment to the broad scientific community, including other domestic agencies and international space agencies, drove the payload definition.

Due to the uniqueness and complexity of many of the experiments, engineering creativity and flexibility were essential during the payload design phase. New hardware was developed and modifications to existing hardware were made to increase reliability and meet science objectives. These efforts included:

- Implementation of planned upgrades to the electronics systems for monitoring, processing, and control
- Incorporation of a biotelemetry capability within the existing RAHF system
- Modifications to the GPWS to support video requirements, data transmission, and experiment unique hardware deployment
- Application of SLS-2 kit development to support the dissection and tissue processing (While some kits were modified, dissection and tissue processing kits were redesigned and brand new kits were developed for efficiency of operations, to meet containment requirements, and stowage considerations.)
- Development of housing to support maternal and nursing behavior in the RAHF
- Modifications to the AEM to allow inflight animal access
- Application of ground tissue fixation techniques (i.e., tissue perfusion, tissue transfer) for operations in microgravity
- Development of new hardware to support animal behavior observations and data recording
- Development of the CEBAS (new middeck hardware) to support aquatic experiments (by DARA)
- Application of the BOTEX (hardware developed to support plant experimentation) to support insect experimentation (by DARA)
- Redesign and development of the VFEU fish package to support biotelemetry (by NASDA)

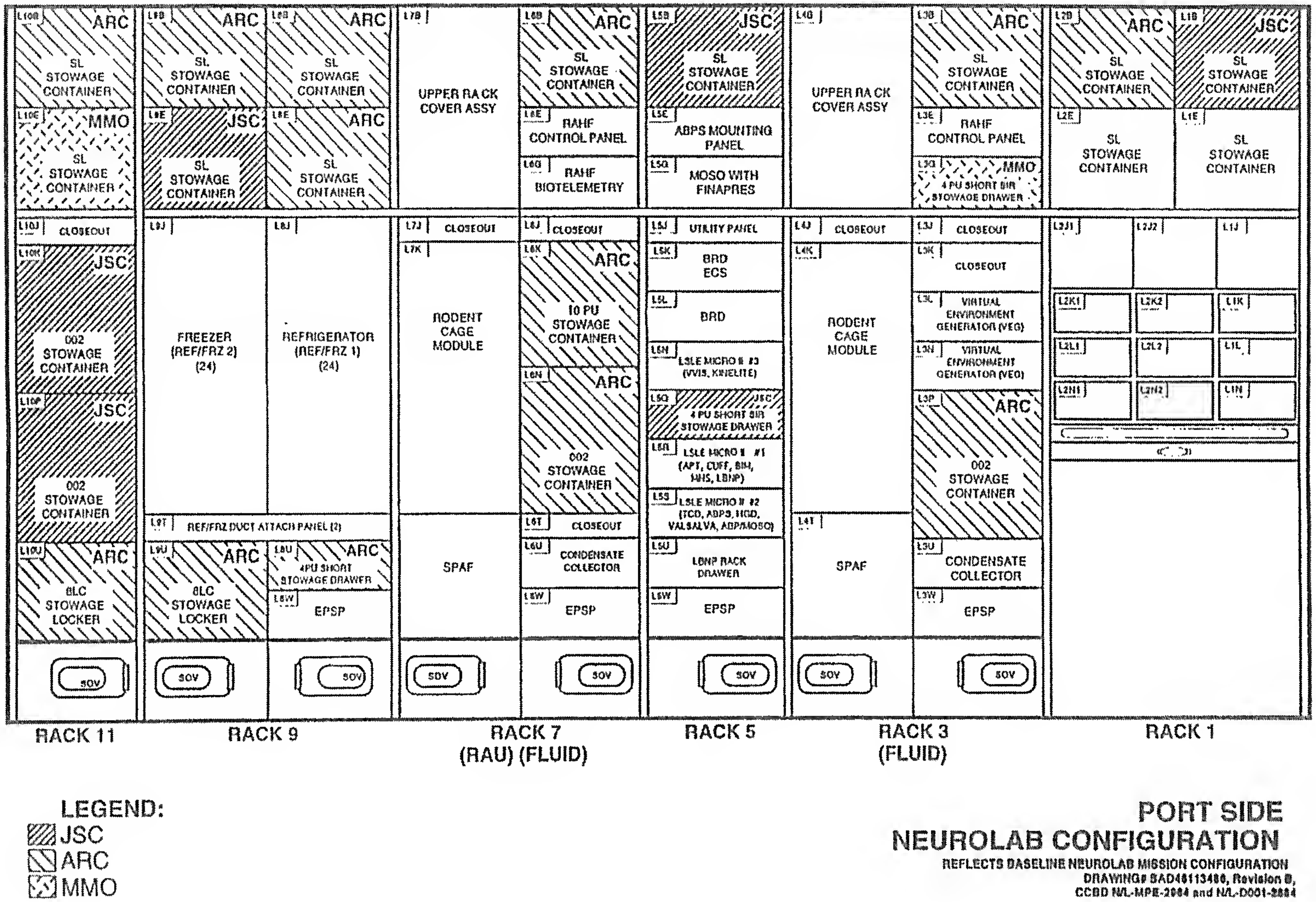

Figure 1.2 Port Side Neurolab Configuration

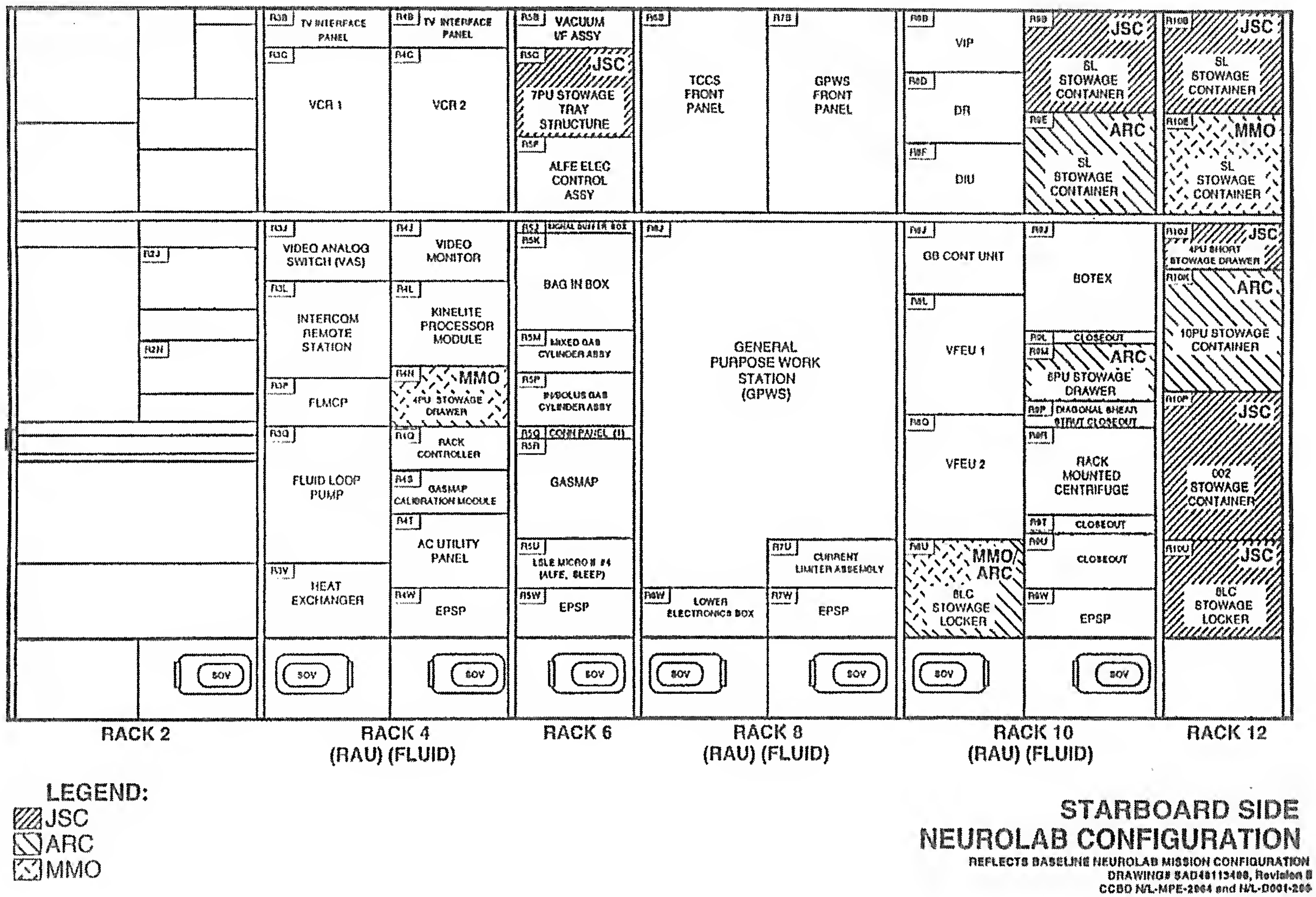

Figure 1.3 Starboard Side Neurolab Configuration

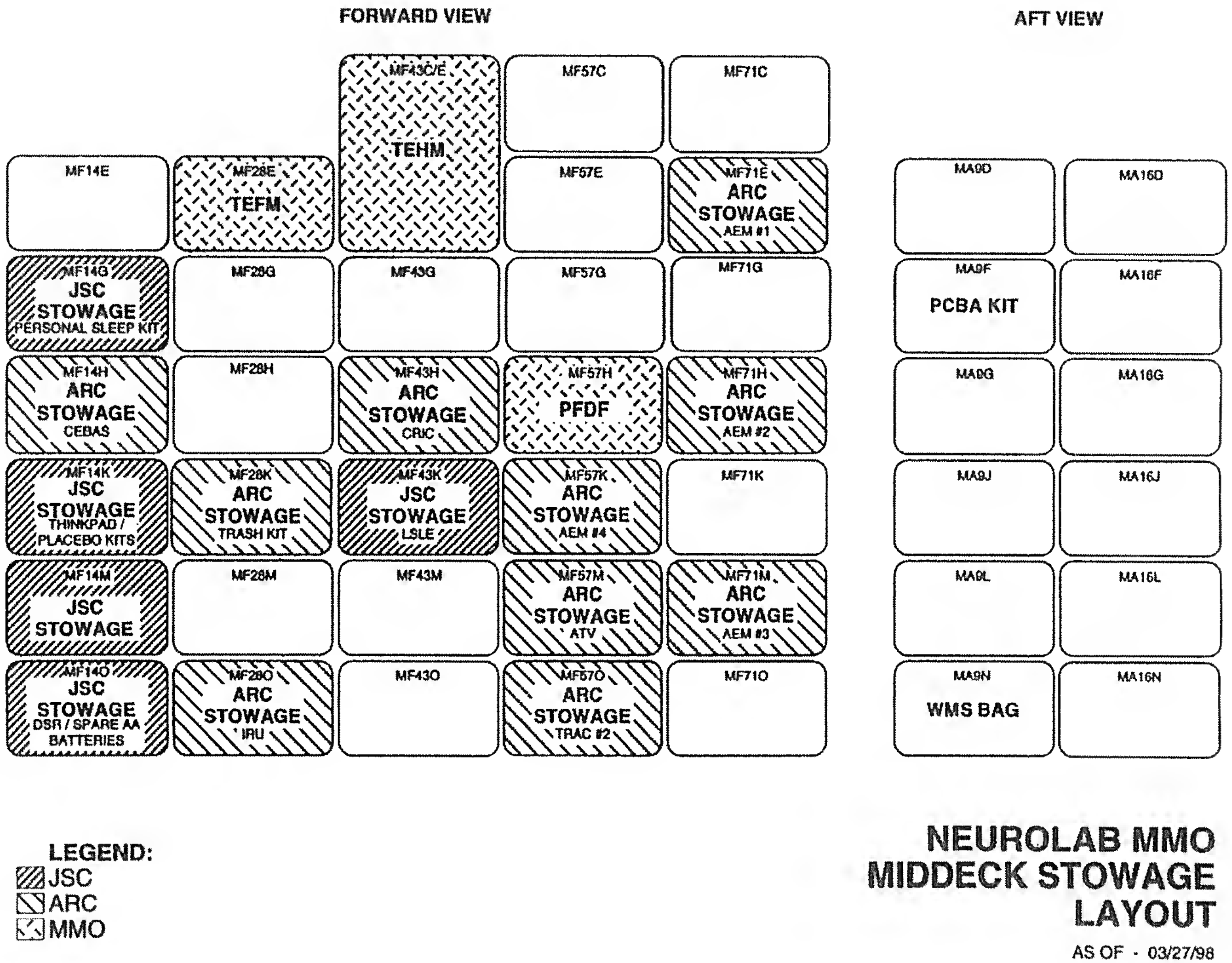

Figure 1.4 Neurolab MMO Middeck Stowage Layout

1.3.2 Payload Development

For previously flown Spacelab missions, four to five years were required to develop a payload for flight. During the first year, payload development requirements were analyzed (crew time, power, stowage), while detailed assessments were provided to HQ regarding funding and schedule. For Neurolab, however, only a small group at ARC participated in the early analysis. Because of the major effort to maximize the science and allow further integration and definition, a payload team was not assembled until experiments were selected for development (three years prior to flight). This decision was also justified on the assumption that reflown hardware would be used and only minimal payload development would be required. However, following the initial assessments, it was recognized that this assumption was incorrect. Several payload development challenges ultimately required an extraordinary effort to meet the launch schedule. The ARC payload development timeline is shown in Table 1.2.

Table 1.2. ARC Payload Development Timeline

Milestone	Date
NASA Announcement of Opportunity for Neurolab (93-OLMSA-01) released	July 1993
ARC received 82 proposals for non-human experiments and performed Engineering Cost Management reviews; delivered to NASA	February 1994
National Institutes of Health (NIH) reviewed for science merit	March 1994
Steering Committee reviewed results and accepted 19 ARC proposals for definition	May 1994
Principal Investigators (PIs) notified	May 1994
Team Leaders identified by NASA HQ met to review Spacelab/mission constraints	June 1994
First Investigators Working Group (IWG) Meeting held to establish 4 teams	August 1994
Science Team Leads met to discuss experiment integration experiment and resource over-subscription issues (e.g., power, stowage, crew time, animal numbers, etc.)	October 1994
ARC, Mission Science, NASA HQ met to review integrated proposal status	January 1995
ARC, KSC met; launch site requirements and support feasibility	February 1995
ARC, Mission Science, NASA HQ met over subscription issues and selection of options	March 1995
NIH conducted review of integrated proposals	April 1995
Steering Committee meeting reviewed options for accommodation	May 1995
Selection for development	June 1995
Initiated development of ARC core hardware elements	July 1995
Preflight operations initiated at KSC	January 1998
Neurolab launch	April 17, 1998
Neurolab landing	May 3, 1998
Postflight operations at KSC complete	June 1998

As previously stated, after experiments were selected for definition, the decision was made to form four integrated science teams that would facilitate cooperation and sharing among investigators. Consequently, PIs had to modify their proposals and work together to submit integrated proposals.

During the year from the formation of the teams to the approval of the integrated proposals, ARC payload development was effectively halted. In addition, Mission Management Office roll-up of required Shuttle resources was also delayed. The decision was made to not proceed with full payload development until integrated proposals were developed. After this delay, ARC Engineering had to develop new experiment configurations and then work with JSC MMO to combine the ARC and JSC payloads. These new experiment configurations determined habitat assignments and thus changed the integrated payload configuration. ARC determined there were

too many experiments to accommodate based on the available resources, but HQ dropped only one PI from the payload.

Staffing was a significant problem for the ARC Neurolab team. A primary issue was re-competition of the support contract, with a contractor corporate merger requiring closure of the existing contract and re-issuance of a consolidated contract. This resulted in NASA being unable to fully staff the payload until late in the development process. The lack of appropriate staffing made it difficult for ARC to determine the scope of the project, plan effectively, and meet important ARC internal and mission milestones.

NASA management had assumed that existing verification documentation for hardware to be reflown would merely be resubmitted. However, in some cases, the supporting documentation was not current or because of hardware modifications, re-verification was required as the hardware did not reflect the previously documented configuration. In addition, as with the NASDA hardware, the supporting test documentation did not reflect the existing verification documentation. This necessitated new testing and verification submittal. The need to retest, rewrite, and resubmit verification documentation posed a major challenge to the ARC Neurolab Payload team.

1.3.3 Payload Accomplishments

Despite the challenges, the ARC payload development resulted in several noteworthy accomplishments that contributed to the overall success of the mission. ARC operated with less funding than the previously flown SLS-2 mission (due to the early assumption that minimal payload development would be required, and hence, the reduced budget), interacted and coordinated with complex PI teams, and integrated NASA and international hardware. The ARC payload had the largest number of Principal Investigators (15) and the most diverse distribution of live specimens ever undertaken by ARC. For example, Neurolab required significantly higher numbers of animals at KSC than previous missions such as the SLS-2 Spacelab mission and the middeck NIH.R3 mission (reference Figure 1.5). Specimens required to support ground controls and launch slips included 6,969 rodents, 30 oyster toadfish, 3,000 swordtail fish, 10,000 water snails, and 10,000 crickets. The payload also had the largest complement of habitats and experiment unique equipment flown to date.

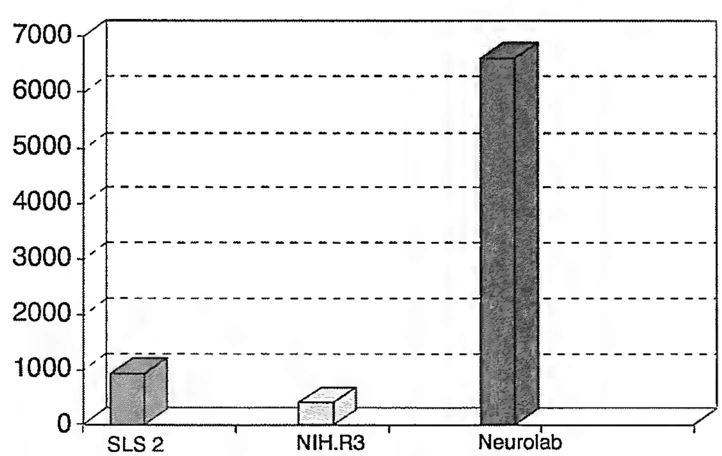

Figure 1.5. Rodent Animal Numbers at KSC: Neurolab vs. SLS-2 vs. NIH.R3

In addition to these accomplishments, Neurolab provided an opportunity for a number of science and engineering firsts in ARC space life sciences research:

- Anatomical studies of the adaptive capability of mammalian brain cells and their neurotransmitters (rodents)
- Use of electrophysiological recording methods to study mammalian brain cell activity patterns (rodents)
- Use of electrophysiological recording methods to study vestibular nerve cells and output characteristics of these sensory cells (fish)
- Accommodation of marine vertebrate species (oyster toadfish)
- Anatomical studies of neonatal development of rat brain and spinal cord, comparable to fetal development in humans
- Studies of the early development of mammalian locomotor system anatomy and behavior (neonatal rat)
- Use of anesthetics and survival surgery in mammals (neonatal rat)
- Use of drugs administered through maternal milk to manipulate and study neonatal growth and development (neonatal rat)
- First rodent perfusion in space
- First flight of mice in the AEM and on the Space Shuttle
- First inflight access to rodents housed in the AEM
- First time four AEMs flown at once on a Shuttle mission.

2.0 Science

2.1 Introduction

Neurolab was the third and last dedicated life-sciences Spacelab mission, as well as the only Shuttle mission dedicated solely to experiments within one scientific discipline, specifically, the study of the nervous system. In preparation for the mission, NASA consulted the neuroscience community to identify critical issues in how gravity affects the nervous system and subsequently released an Announcement of Opportunity in 1993, which drew 172 proposals. After a peer review evaluation process, NASA selected 32 experiments for flight; 26 flew on Neurolab and six subsequently flew on other Shuttle flights. Of the 26 Neurolab experiments, 15 were managed by Ames Research Center (ARC). The ARC experimental subjects consisted of rats, mice, oyster toadfish, swordtail fish, snails, and crickets.

The primary goal of all the experiments manifested on Neurolab was to understand how the nervous system develops and functions in space, with a focus on the consequences of long-term space flight. However, investigators also hoped to increase the general knowledge of how the nervous system develops and functions on Earth and contribute to the study and treatment of neurological diseases and disorders.

Some of the basic questions were studied across several experiments:

- Since we learn to move with gravity present, how can we adapt so quickly to function without gravity?
- How do gravity-sensitive parts of the body like the inner ear, cardiovascular system, and muscles adapt to an environment without apparent gravity?
- Why are sleep and biological rhythms changed in space?
- Will an inner ear that developed in space function the same as one that developed on Earth?
- Is normal motor function affected by gravity?

To facilitate tissue sharing and cooperative optimization of science objectives, NASA divided investigators into four science discipline teams: Neuronal Plasticity, Mammalian Development, Aquatic, and Neurobiology. For each team, descriptions of relevant science objectives, project science data (collected by ARC) and PI-approved experiment profiles (including results) follow.

2.2 Neuronal Plasticity Team

The Neuronal Plasticity (NP) team studied how balance, daily biological rhythms, and the control of movement change in microgravity. The objective of the NP group of investigators was to assess and quantify changes in the adult mammalian central nervous system as it adapts to the microgravity environment and as it readapts to gravity on Earth. Investigators and experiments in the NP team are listed in Table 2.1.

Table 2.1. Neuronal Plasticity Team Investigators and Experiments

Investigator	Experiment #	Experiment Title
Charles A. Fuller University of California, Davis	E132	CNS Control of Rhythms and Homeostasis during Space Flight
Gay R. Holstein Mount Sinai School of Medicine	E127	Anatomical Studies of Central Vestibular Adaptation
Bruce L. McNaughton University of Arizona	E100	Ensemble Neural Recording of Place Cells in Rats during Space Flight
Ottavio Pompeiano University of Pisa, Italy	E118	Effects of Microgravity on Gene Expression in the Brain
Muriel D. Ross NASA Ames Research Center	E085	Multidisciplinary Studies of Neural Plasticity in Space

The NP team performed their experiments on Fischer 344 adult male rats. Of the 28 rats flown on the mission, four were used exclusively for McNaughton's experiment, with the remaining 24 forming the Integrated Neuronal Plasticity (INP) group, divided between the other four investigators. Table 2.2 shows experiments and controls associated with each animal group.

Table 2.2. Neuronal Plasticity Team Animal Groups and Controls

Animal Group	# of Experiments Supported	Controls
Adult Fischer 344 male rats, n=24 (housed in the Research Animal Holding Facility (RAHF))	4 (E085, E118, E127, E132)	Vivarium controls (48 hours delayed), n=24 Simulated Caged controls (96 hours delayed), n=24 (housed in Sim-RAHF cages)
Adult Fischer 344 male rats, n=4 (housed in the Animal Enclosure Module (AEM))	1 (E100)	Conducted in PI laboratory

The rodents used in McNaughton's experiment underwent surgical implantation of an electrophysiological recording/limbic stimulation head implant at L-30/28 days. These animals were housed in two Animal Enclosure Modules (AEMs), which provided all necessary life-support functions. (Reference 3.2.1 in the Hardware section for a description of the AEM).

The 24 INP rodents underwent surgical implantation with physiological biotelemetry units approximately two months prior to flight. The transmitters allowed wireless collection of heart rate, body temperature, and an index of general activity. For the mission, 12 of the 24 implanted rodents were housed in cages equipped to receive and transmit the telemetry signals to the onboard Data Acquisition System.

The INP rodents were housed in the Research Animal Holding Facility (RAHF). Like the AEM, the RAHF provided all necessary life-support functions for the rodents. (Reference 3.2.10 in the Hardware section for a description of the RAHF hardware.)

2.2.1 Neuronal Plasticity Project Data

Data included below are for the INP rodents and were collected by the ARC project. Food and water consumption and body weight data for the animals used in McNaughton's experiment were collected by the PI team and are not provided below.

Animal Health and Behavior — Postflight, all animals were determined to be in good general health.

Body Weight and Weight Gain — Body weights among the Flight, Vivarium, and Sim-Caged animals were not significantly different at loading in the Research Animal Holding Facility (RAHF) (reference Table 2.3).

Table 2.3. Mean Body Weight at RAHF Cage Load (n=24 rats)

Experiment Group	Mean Weight (g)	Standard Error
Flight	366.795	3.502
Vivarium	358.554	3.583
Sim-Caged	361.554	2.66

Flight animal body weight was significantly less than both controls at landing (reference Table 2.4). Conclusions have not been made as to why Flight animals had lower weights at landing but consumed more food and water inflight than did Vivarium and Sim-Caged animals. (Flight food and water data are shown in Tables 2.7 and 2.8.)

Table 2.4. Mean Body Weight at RAHF Cage Unload (n=11 rats)

Experiment Group	Mean Weight (g)	Standard Error
Flight	349.93	4.524
Vivarium	371.17	3.41
Sim-Caged	373.73	4.984

Body weights taken prior to dissection on Recovery + 13 (R+13) days were not significantly different across groups (reference Table 2.5).

Table 2.5. Body Weight at R+13 (n=6 rats)

Experiment Group	Mean Weight (g)	Standard Error
Flight	368.967	7.87
Vivarium	380.267	5.76
Sim-Caged	388.883	13.62

Food — Preflight foodbar consumption was similar across the Flight, Vivarium, and Sim-Caged groups (reference Table 2.6).

Table 2.6. Food Consumption Launch-29 (L-29) to L-3 days (n=24 rats)

Experiment Group	Mean per Day (g)	Standard Error
Flight	18.07	0.244
Vivarium	18.59	0.181
Sim-Caged	17.67	0.171

Flight animal food consumption was significantly higher than both control groups during the flight period (reference Table 2.7). No explanation has been provided to explain this observation.

Table 2.7. Total Food Consumption during Flight (n=11 rats)

Experiment Group	Mean (g)	Standard Error
Flight	359.52	7.83
Vivarium	312.95	5.586
Sim-Caged	304.22	6.682

Water — Flight data indicates that daily water usage was significantly higher for the Flight group than for the controls (reference Table 2.8). No explanation has been provided to explain this observation.

Table 2.8. Daily Water Usage FD 1– FD 15 (n=11 rats)

Experiment Group	Mean (ml/day)	Standard Error
Flight	27.48	0.658
Vivarium	13.3	0.191
Sim-Caged	13.36	0.201

2.2.2 Neuronal Plasticity Experiments

Fuller, Charles A. ***CNS Control of Rhythms and Homeostasis during Space Flight*** —

Objectives: Research has shown that the static gravitational field of the Earth and the dynamic cyclic changes caused by the Earth's rotation are two important selective pressures that shaped the evolution of biological organisms. Many features of an animal's physiology and behavior are a consequence of both static and dynamic geophysical influences. The circadian timing system (CTS) is one important temporal organizer controlling both physiology and behavior. Animals (including humans) exposed to microgravity exhibit alterations in both CTS function and homeostasis. These experiments examined the effects of space flight on the physiology of the CTS and the homeostatic control system of animals, specifically: 1) circadian rhythms; 2) neural responses of the circadian pacemaker and the sensory pathway for light information from the retina to the CTS; 3) adaptations in homeostatic regulation; and 4) neural changes in hypothalamic nuclei that regulate specific homeostatic functions.

Approach: Six flight rats and ground control rats (six flight simulated and six vivarium controls) were utilized in one set of experiments. Twelve flight rats and two sets of ground control rats (12 simulated and 12 vivarium) were used in another set of experiments. The rodents were implanted with biotelemetry units to monitor circadian rhythms of body temperature, heart rate, and activity. In addition, eating and drinking was monitored for all rats. To examine the space flight effect on circadian and homeostatic regulation of physiological and behavioral functions, rats were exposed to 24-hour light/dark cycles (LD) consisting of 12 hours of light (approximately 30 lux) followed by 12 hours of darkness. The circadian rhythms and daily mean of rat body temperature, heart rate, feeding, drinking and activity (as a measure of homeostasis) were compared. To examine the space flight effect on free-running circadian rhythm characteristics, a subset of rats was maintained in a constant light condition (LL). Data were analyzed to determine circadian rhythms and results were compared to those of rats exposed to 24 -hour light/dark cycles. To examine the space flight effect on the pattern of c-Fos synthesis in hypothalamic nuclei, and whether it alters the effect of light pulses to induce c-Fos expression in the central nervous system, one group of rats received a one-hour pulse of light during the dark cycle. Another group was not exposed to a pulse of light. The brains and eyes from both groups were then removed and sections of the hypothalamus were histochemically stained for c-Fos reactive neurons.

Results: The LL flight rats exhibited an increase ($p<0.001$) in free-running period of body temperature and heart rate relative to controls. The periods returned to preflight values after landing. The LL flight animals maintained internal phase angle relationships between rhythms compared with controls. The LD flight rats remained entrained to the LD cycle; however, they evidenced a pronounced phase delay in body temperature, suggesting an increase in period,

compared to controls. The LD flight rats also demonstrated a decrease in body temperature and a change in the daily waveform compared to controls. Both the LD and LL flight rats and controls exhibited an increase in heart rate, suggesting a possible caging effect. Finally, the Flight Day 2 flight animals demonstrated a reduced sensitivity to light as evidenced by highly attenuated c-Fos immunoreactivity in the SCN compared to controls. The sensitivity to light of the flight animals returned to preflight and control levels by Flight Day 14. These findings demonstrate that microgravity affects the circadian clock, including the clock's ability to maintain temporal organization and to properly entrain to an external LD cycle.

Holstein, Gay R. ***Anatomical Studies of Central Vestibular Adaptation —***

Objectives: Alterations in sensory and motor function occur during weightlessness. The vestibular abnormalities experienced by astronauts include immediate-reflex motor responses, sensations of rotation, nystagmus, dizziness and vertigo, and space motion sickness. Adaptation to the microgravity environment usually occurs within one week. The mechanisms underlying this adaptation process have not been completely elucidated. This experiment studied the neuronal basis for microgravity-induced changes in the vestibular system. The specific objectives were 1) to assess the quantitative differences in cerebellar synaptic morphology and ultrastructure of flight rats compared to controls; 2) to study the qualitative and/or quantitative differences in excitatory amino acid neurotransmission in the nodulus and flocculus of flight rats compared to controls; and 3) to evaluate the qualitative and/or quantitative differences in GABAergic neurotransmission in the nodulus and flocculus of flight rats compared to controls.

Approach: Brain tissue was taken from both flight and ground control animals on flight day two (FD 2), FD 14, recovery day one (R+1) and R+13. The entire cerebellum was fixed and the tissue processed for stereological analysis, immunocytochemical studies of excitatory amino acid neurotransmission, and immunocytochemical studies of GABAergic Purkinje cell interactions. Thin wafers of cerebellar tissue were cut, embedded in plastic, and examined by light microscopy. The tissue wafers were then traced using a Trisimplex projector. The tracings were used to estimate the volume of the nodulus and the partial volume fraction occupied by the molecular layer of the nodulus for each subject. After volume measurement, selected thin sections were obtained from four wafers from the FD 2 rats and prepared for ultrastructural, quantitative, and post-embedding immunocytochemical studies.

Results: Cytoplasmic and neuropil alterations were observed in sections from the flight animals that were not apparent in the controls. Throughout entire nodular Purkinje cells (including somata, dendrites, thorns, and axon terminal) the smooth cisterns of endoplasmic reticulum were substantially more complex in flight animals than controls. Some enormous mitochondria were found in the Purkinje cell somata of flight animals, and enhanced glial sheathing between Purkinje cells and granule cells was also observed. Neuropil alterations included frequent, sometimes large protrusions of neuronal elements into neighboring profiles, suggesting enhanced fluidity of neuronal shape. Ultrastructural indications of degeneration and synaptic reorganization were also observed in the nodular molecular layer of flight animals. The above morphologic changes were not apparent in control animals. These preliminary results provide ultrastructural evidence for neuronal and synaptic plasticity in the nodulus of adult rats after 24 hours of exposure to space flight.

McNaughton, Bruce L. ***Ensemble Neural Coding of Place and Direction in Zero-G —***

Objectives: Brain cells in the hippocampus play an important role in the ability of animals to orient themselves within their environment. Called place cells, they encode a mental map of the environment, which is then used to remember locations and determine routes between them. Another class of neurons associated with spatial orientation, called head direction (HD) cells, are located in the thalamus and limbic cortex. Firing properties of the place cells in the hippocampus and HD cells are tightly coupled; one function of the HD cells may be to orient the acquired cognitive map in the hippocampus. The fact that this orientation system is based on information with respect to gravity suggests that problems may develop in low gravity conditions leading to an inability of the hippocampus to develop stable place codes. The purpose of this experiment was to study how the hippocampal neural representations of place and direction are affected by zero-gravity conditions in rats performing tasks requiring navigation in three dimensions.

Approach: The first part of the experiment addressed the question of whether the hippocampal place system can maintain stable representations of the environment under zero-G. Three rats were singly tracked with two position-image-locator cameras synchronized with a data acquisition system as they navigated a special walking apparatus. The walking apparatus consisted of three orthogonal planes in which a track permits the animal to walk in a continuous loop, having three 90 degree turns in its yaw axis interspersed with three 90 degree backward pitches. When the animal returns to the origin, it has completed only 270 degrees of yaw. Animals were implanted with probes that monitored neuronal spikes simultaneously from about 20 or more hippocampal neurons, to determine whether they fired in a stable fashion with respect to the rat's location in three-dimensional space. In the second part of the experiment, rats were trained to visit each of four arms on a two dimensional cross-shaped track. The rat was then rotated 180 degrees in the pitch axis followed by a 180-degree rotation in the roll axis; as a result, the rat faced 180 degrees opposite its original position without experiencing rotation in the yaw axis. The animals were tracked as above to determine whether place cells fire in synchronization with the rat's spatial location relative to the track or relative to the reference frame of the work volume of the General Purpose Work Station.

Results: During the first zero-G recording session on FD 4, rat 2 did not show strong spatial tuning in any of the cells that fired while on the track. In contrast, this animal had normal, highly specific place fields in cells that fired when tested on a very similar track four days before launch. A spatial-tuning index for rat 2 was significantly different between preflight and FD 4 recordings. Rat 1 exhibited a different pattern of abnormal spatial selectivity; almost all the spatially-selective firing recorded occurred when the rat moved its head off the track. In contrast to rats 1 and 2, rat 3 displayed normal spatial tuning on FD 4; however, these data came from the animal's second run on the track. Data from the first run were lost due to technical difficulties, so it remains unknown if the animal gained spatial experience during the first trial. Spatial selectivity of rats 1 and 2 improved by FD 9, showing hippocampal adaptation. The main conclusion is that, contrary to the original hypothesis, the rat hippocampus is capable of forming a stable code for three dimensional space under low gravity conditions; however, the development of this code may be somewhat slower than under normal gravity conditions.

Pompeiano, Ottavio. ***Effects of Microgravity on Gene Expression in the Brain —***

Objectives: The mammalian brain exposed to space flight experiences profound changes in neuronal activity. Immediate early genes (IEGs), such as c-fos and Fos-Related Antigens

(FRA), are useful indicators of changes in neuronal activity and plasticity. Within minutes of exposure to neural stimulation, the mRNA levels of these genes increase. The corresponding proteins can be detected for hours (Fos) or days (FRA) afterwards. These proteins may act as messengers to regulate the transcription of target genes involved in the physiological responses and adaptation to μG or readaptation to 1 G. This experiment investigated whether changes in IEG expression, occurring during space flight, affect brain structures involved in the control of: a) somatic (postural and motor) functions; b) vegetative (cardiovascular, respiratory and gastrointestinal) functions; and c) the regulation of the sleep-waking cycle. These changes were investigated to see if they depend on alterations in neuronal activity induced by macular gravity signals and, if so, whether they could be related to or modified during different phases of the sleep-waking cycle.

Approach: Flight rats used in this study were part of the integrated adult rat dissections performed on FD 2 and FD 14. Postflight, remaining animals were sacrificed at different days after landing (R+1 and R+13, respectively). Simulated Caged Control (SIM) and vivarium animals were sacrificed on a 48-hour and 96-hour delayed basis. All brain tissue, excepting the cerebellum, was used in this experiment. Adjacent sections of the same brain tissues were alternatively stained with either a Fos or a FRA antibody, to mark both short- and long-lived responses to changes in gravity stimulus. These were characterized by hypergravity followed by exposure to μG at FD 2 after launch, stabilization to μG at FD14, hypergravity followed by exposure to 1 G at R+1 after landing, stabilization to 1 G at R+13. Tissue was removed from the fixative, cryoprotected in 30% sucrose solutions in phosphate buffer (PB) at 4 °C, frozen, and sectioned into 40 μm sections with a cryostat. Immunocitochemistry was used to detect Fos and FRA proteins in the forebrain and brainstem. The distribution of labeled cells in each brain region was examined and quantified. The number of labeled cells was compared between flight and SIM groups.

Results: Variable numbers of Fos- and FRA-positive cells were found during different space flight conditions in Medial (MVe) and Spinal Vestibular nuclei (SpVe), which contribute to the vestibulo-ocular and the vestibulo-collic reflex, and in Group F nuclei, which projects to the vestibulocerebellum. In particular, all these structures showed a small increase in Fos and FRA expression at FD2, due to exposure to hypergravity partially compensated by exposure to μG, while a prominent increase of this expression occurred at R+1, due to hypergravity followed by exposure to 1 G. Similar changes in Fos and FRA expression occurred in the Area Postrema, which appears to be involved in the development of motion sickness, in the Nucleus of the Solitary Tract (NST) and the related ventrolateral reticular structures, which intervene in the central and reflex regulation of cardiovascular and respiratory activities, and finally in the Central nucleus of the Amygdala.

An increased level of Fos expression occurred in the noradrenergic Locus Coeruleus nucleus (LC) of flight rats with respect to ground controls, without variations at different time points of the space flight. However, the number of FRA-positive cells selectively increased in the LC of flight animals sacrificed at FD 2 and more prominently at R+1. These differences were attributed to the fact that, while the Fos protein induced by the gravity force returns to basal levels within hours after stimulation, thus being undetected 24 h after launch or the reentry, FRAs persist for days after induction. Since activity of noradrenergic LC neurons has been shown to produce gene expression in several target structures, it is likely that the long-lasting induction of FRAs in the LC at FD 2 and more prominently at R+1 contributes to the molecular changes occurring in the vestibular and the related structures indicated above.

An increase in Fos expression was also observed in the spinal areas of both the Inferior Olive (IO) and the Lateral Reticular nucleus (LRt) at FD 2 and FD 14, i.e., during and after the launch. However, only few labeled cells were observed in these precerebellar nuclei at R+1 and R+13. This last finding was partly attributed to reduced somatosensory and motor activities occurring at these specific time points of the space flight.

In addition, the increase in gravity force at R+1 selectively increased the number of FRA-positive cells in the dorsomedial cell column of the IO (which corresponds to the vestibular area of this structure), while no such changes affected the Fos expression. This increase in gene expression could then be detected by using only a long-lasting (FRA) and not a short-lasting (Fos) marker of neuronal plasticity.

The results of this experiment indicate that the gravity force acts on specific vestibular nuclei and related structures controlling somatic and vegetative functions, and that the noradrenergic LC neurons, driven by the gravity force, may contribute to long-term molecular changes occurring in the brain during adaptation to μG and readaptation to 1 G. Changes in gene expression in forebrain structures, such as the cerebral cortex, were finally used to identify the different phases of the sleep-waking cycle and relate the molecular changes occurring during different time points of the space flight to the animal state.

Ross, Muriel D. ***Multidisciplinary Studies of Neural Plasticity in Space —***

Objectives: Ribbon synapses in the hair cells of the inner ear transmit information to the brain about linear acceleration forces acting on the body. This experiment was designed to build upon previous data collected on Spacelab Life Sciences 1 and 2 (SLS-1 and SLS-2), which showed that the ribbon synapses of gravity-sensor hair cells changed in number, kind, and distribution during space flight, a phenomenon known as neural plasticity. The three major points of interest in this study were 1) whether the ribbon synapses would rapidly increase in number upon initial exposure to weightlessness; 2) whether the changes observed early in flight would remain stable throughout the flight (expecting an initial overshoot as the body compensates for the new environment); and 3) whether different parts of the gravity sensors would show different synaptic counts.

Approach: Flight rats used in this study were part of the integrated adult rat dissections performed on FD 2 and FD 14. Inner ear tissues were removed from four rats on FD 2, nine rats on FD 14, six rats 2 days postflight, and six rats 14 days postflight. In addition, tissues were taken from 10 basal controls on FD 2. Labyrinth dissection, microdissection, tissue preparation, and statistical analysis were performed as described in Ross 1993, 1994, 2000, except that the Neurolab study concentrated on the striolar macular area rather than on the posterior border. Only one of the four utricular maculae from FD 2 was in condition for transmission electron microscopy. To compensate for lost data, the saccular maculae were also examined.

Results: Although findings from the utricular maculae must be considered anecdotal due to small sample size, the analysis provided several interesting results. The most important findings can be summarized as follows: 1) By FD 2, an upward change in the mean number of synaptic ribbons could already be observed in macular vestibular hair cells. 2) A decline from FD 2 values occurred in both kinds of hair cells by FD 14. 3) On both FD 2 and FD 14, increments in synaptic means were prominent in Type II hair cells and were significant compared to the basal. 4) Mean values of synapses for Type II hair cells of the striolar area were lower than those found previously in SLS-2. All these findings support previous evidence that changes in synaptic

ribbons of utricular gravity sensor hair cells occur rapidly in weightlessness, and that the changes are more prominent in Type II hair cells. The decline seen in the striolar area by FD 14 is a new observation, suggesting a synaptic overshoot on FD 2.

A more interesting finding, perhaps, is that the striolar area of the saccular macula did not show the same changes in synapses observed in the utricular macula. The saccular macula has been studied in one basal, two FD 2, two FD 14 and one PFD 2 (postflight day 2) samples. Results indicate that the Type I synapses had decreased by FD 2, but were up again by FD 14 (FD 2 to FD 14, significant) and remained above FD 2 at PFD 2. Synapses in Type II cells remained relatively stable throughout the period of the experiment. It is noteworthy that the number of processes on Type II hair cells of the saccule were less numerous than those observed previously in the utricular macula.

Overall, the results provide the first evidence that maculae, and macular location (defined by variation in otoconial distribution, hair cell morphology, and vestibular afferent wiring) are related to the range of synaptic changes observed in weightlessness. The differences in saccular versus utricular macular results indicate that the two maculae have differing functional (and integrative) responses to translational and gravitational forces acting on the systems.

2.3 Mammalian Development Team

The Mammalian Development (MD) team focused on whether or not gravity is essential to normal development. MD experiments studied the development of muscles, the vestibular system, the cardiovascular system, and many parts of the brain. The overall objective of the MD team was to assess and characterize mammalian central and peripheral nervous system development at the cellular, system, and behavioral levels in 1- and micro-G environments. Investigators and experiments in the MD team are listed in Table 2.9.

Table 2.9. Mammalian Development Team Investigators and Experiments

Investigator	Experiment #	Title
Kenneth M. Baldwin University of California, Irvine	E103	Neural-Thyroid Interaction on Skeletal Isomyosin Expression
Kenneth S. Kosik Brigham & Women's Hospital, Harvard	E123	Neuronal Development under Conditions of Space Flight
Richard S. Nowakowski University of Medicine & Dentistry of New Jersey, Piscataway, NJ	E093	Reduced Gravity: Effects in the Developing Nervous System
Jacqueline Raymond Université de Montpellier II, France	E143	Microgravity and Development of Vestibular Circuits
Danny A. Riley Medical College of Wisconsin, Milwaukee	E122	Effects of Microgravity on Neuromuscular Development
Tsuyoshi Shimizu Fukushima M. Coll, Japan	E034	Postnatal Development of Aortic Nerves in Space
Kerry D. Walton NYU Medical Center, New York	E150	Effects of Gravity of Postnatal Motor Development

PIs Shimizu, Baldwin, Riley, Kosik, Raymond, and Walton's experiments used neonatal rats at post-natal day (PN) 8. Each experiment had two primary litters and these 12 families (one dam and eight neonates per family) were housed one family per cage in the RAHF (P7 group). During flight, two litters were dissected. Tissues collected inflight and postflight were shared across all PIs. Walton was also assigned two families of PN 14 neonates with dams that flew in the AEM

(P13 group). Nowakowski's experiment used timed-pregnant mice at three different stages of pregnancy and were housed in an AEM. Table 2.10 shows experiments and controls associated with each animal group.

Table 2.10. Mammalian Development Team Animal Groups and Controls

Animal Group	# of Experiments Supported	Controls
Neonate Rats *(Rattus norvegicus)*: Post-natal day 8 at launch, n=12 families (housed in the Research Animal Holding Facility (RAHF))	6 (E034, E103, E122, E123, E143, E150)	Simulated Caged controls (housed in Sim-RAHF cages) (8 days delayed) Vivarium control (4 days delayed)
Neonate Rats *(Rattus norvegicus)*: Post-natal day 14 at launch. n=2 families (housed in the Animal Enclosure Module (AEM))	1 (E150)	Simulated Cage controls (housed in Sim-AEM cages) (8 days delayed) Vivarium control (4 days delayed)
Pregnant mice *(Mus musculus)*: 3 different stages of pregnancy, n=18 animals (housed in the Animal Enclosure Module (AEM))	1 (E093)	Simulated Cage controls (housed in Sim-AEM cages) (4 days delayed) Vivarium control (2 days delayed)

Osmotic pumps were surgically implanted preflight into one of the P7 litters assigned to Baldwin. The administered drug induced a thyroid-deficient state in the dam as well as the nursing neonates. The second litter assigned to Baldwin served as a euthyroid (normal) control.

MD rodents were housed in either the AEM or RAHF, which provided all necessary life-support. (Reference 3.2.1 and 3.2.10 in the Hardware section for a description of the hardware items.)

2.3.1 Mammalian Development Project Data

Animal Health and Behavior — Mice remained healthy on orbit. Since all mice were dissected inflight, no postflight data were collected.

Overall, P7 neonates did not fare well in the RAHF environment in microgravity and experienced a high inflight mortality rate (approximately 50%). To maximize recovery for surviving neonates, some were transferred inflight to dams that appeared more adept at rearing neonates in microgravity. For a detailed description of these inflight operations, reference pp. 85-86 in the Operations section.

Body Weight and Weight Gain —

P7 Dams:

Body weights were not significantly different between groups either pre- or postflight. However, while the mean body weight of Sim-Caged dams increased slightly and Vivarium-housed dams decreased slightly from load to unload, the mean body weight of Flight dams decreased by 15 grams from load to unload (reference Table 2.11). The data are open to various interpretations, (though the weight decrease in Flight dams may have been related to lactation and nursing behavior); however, it is clear that housing dams in Sim-Cages while on the ground had no obvious detrimental effect.

Table 2.11. P7 Dam Average Cage Load and Unload Weights (n=12 rats)

Experiment Group	Preflight (load)	Standard Error	Postflight (unload)	Standard Error
Flight	270.9	4.6	255.2	6.5
Vivarium	262.0	4.0	257.0	4.8
Sim-Caged	267.4	7.9	273.1	7.7

P7 Litters:

Cross-fostering of litters (litter equalization) was done based on date and time of birth, and neonate weight and sex to meet Pl science objectives (reference Table 2.12). The method for litter equalization was determined together with the PIs and implemented by the project.

Table 2.12. PN2 Litter Equalization

	Litter Weight Range (g)	Individual Weight Range (g)	Number of Animals per Litter
Natural Litters	59.6 to 107.6	5.0 to 10.4	10 to 18
Cross-fostered Litters	58.3 to 62.7	6.8 to 8.6	8

After litter equalization, at cage load, average litter weights for the Flight, Vivarium, and Sim-Caged groups did not differ significantly (reference Table 2.13).

Table 2.13. PN6 Litter Selection/Cage Load (n=12 litters per group)

Experiment Group	Litter Weight Range (g)	Individual Weight Range (g)	Number of Animals per Litter
Flight	119.05 to 133.45	13.21 to 17.92	8
Vivarium	110.30 to 130.41	12.10 to 17.61	8
Sim-Caged	113.63 to 132.82	13.25 to 17.90	8

Flight neonates experienced a significant mortality rate during the mission. The Flight neonates that survived weighed significantly less than the corresponding Vivarium and Sim-Caged neonates. However, due to the stress experienced by Flight animals, low body weight cannot be automatically attributed to microgravity alone. Various factors, including a difficulty of the dam to maintain an appropriate nursing posture that would keep the neonates close, may have contributed to low weight gain observed in the neonates.

Due to the reorganization of the neonates inflight, many neonates returned postflight in different cage slots and with different dams. Therefore, comparison of pre-and postflight weights per litter was not performed as it would not have yielded any relevant information. Table 2.14 shows unload body weights for the surviving flight animals; Tables 2.15 and 2.16 show body weights for all Vivarium and Sim-Caged animals, respectively.

Table 2.14. Cage Unload Body Weights for Surviving Flight Animals

RAHF Cage Slot	Number of Surviving Neonates	Litter Weight (g)	Average Individual Weight (g)	Standard Deviation
1	3	105.72	35.24	8.74
2	0	n/a	n/a	n/a
3	5	299.1	49.85	5.27
4	4	124.05	31.01	6.53
5	4	192.13	48.03	5.96
6	1	48.57	48.57	n/a
7	0	n/a	n/a	n/a
8	0	n/a	n/a	n/a
9	2	103.61	51.81	3.37
10	1	35.04	35.04	n/a
11	6	309.71	51.62	8.30
12	1	31.74	31.74	n/a

Table 2.15. Cage Unload Body Weights for All Vivarium Animals

Vivarium Cage Slot	Litter Weight (g)	Average Individual Weight (g)	Standard Deviation
1	n/a*	n/a*	n/a*
2	n/a*	n/a*	n/a*
3	734.93	91.87	3.91
4	335.89	41.99	2.52
5	685.56	85.70	5.48
6	n/a	n/a	n/a
7	690.89	86.36	3.70
8	672.46	84.06	4.74
9	697.99	87.25	2.39
10	722.77	90.35	3.90
11	680.22	85.03	3.86
12	700.12	87.52	5.61

* dissected during the mission to match nominal on-orbit operations

Table 2.16. Cage Unload Body Weights for All Sim-Caged Animals

Sim-Cage Cage Slot	Litter Weight (g)	Average Individual Weight (g)	Standard Deviation
1	n/a*	n/a*	n/a*
2	n/a*	n/a*	n/a*
3	698.57	87.32	3.84
4	311.52	38.94	1.42
5	646.84	80.86	5.71
6	n/a	n/a	n/a
7	701.68	87.71	4.88
8	657.48	82.19	5.28
9	578.76	72.35	9.14
10	581.03	72.63	5.66
11	621.42	77.68	3.27
12	638.85	79.86	5.62

* dissected during the mission to match nominal on-orbit operations

Litter weights were not significantly different between Flight (surviving animals), Vivarium, and Sim-Caged litters at R+30 (reference Table 2.17).

Table 2.17. P7 Litter Weights at R+30

Group	P7 R+30 means	P7 R+30 Standard Error Means
Flight	204.7	18.5
Vivarium	201.6	10.1
Sim-Caged	181.9	7.1

P13 Dams: No statistical analyses were performed on these data since there were only two dams per group (Flight, Vivarium, Sim-Caged). Body weights were similar across the groups at cage load and unload. Cage unload weights for the Flight and Sim-Caged dams were somewhat less than at cage load; however, body weights for the Vivarium dams were virtually identical at load and unload measurements (reference Table 2.18).

Table 2.18. P13 Dam Weights at Cage Load and Unload

Dam	Preflight Weight (g) (load)	Postflight Weight (g) (unload)
Flight 1	273.48	247.22
Flight 2	267.93	233.93
Vivarium 1	263.78	269.51
Vivarium 2	255.23	253.67
Sim-Caged 1	274.34	254.71
Sim-Caged 2	311.18	303.41

P13 Litters: Weights at cage load were not significantly different between the Flight and Sim-Caged litters; however, the Vivarium animals were significantly smaller than the other litters (reference Table 2.19).

Table 2.19. P13 Litters Cage Load Weights
(n=7 neonates per litter; 2 litters each experiment group)

Experiment Group	Weight (g)	Standard Deviation (among neonates)
Flight, litter 1	227.34	0.40
Flight, litter 2	230.46	2.47
Vivarium, litter 1	208.31	1.80
Vivarium, litter 2	201.12	4.39
Sim-Caged, litter 1	238.86	3.26
Sim-Caged, litter 2	230.92	3.02

Litter weights at cage unload were not significantly different between the Flight and Sim-Caged litters; however, the Vivarium animals were significantly heavier than the other two groups (reference Table 2.20).

Table 2.20. P13 Group Cage Unload Weights
(n=7 neonates per litter; 2 litters each experiment group)

Experiment Group	Weight (g)	Standard Deviation (among neonates)
Flight, litter 1	763.45	3.67
Flight, litter 2	696.33	8.42
Vivarium, litter 1	880.50	8.77
Vivarium, litter 2	796.10	13.05
Sim-Caged, litter 1	714.92	9.83
Sim-Caged, litter 2	696.46	16.14

Food —

P7: Preflight food bar acceptance rates for pregnant (P7) dams were similar across all the groups (n=48 dams/group).

Due to the reorganization of the neonates inflight, accurate gross food consumption data per litter in the P7 group could not be determined.

P13: Food intake was similar across all Flight, Vivarium, and Sim-Caged families, with the exception of Vivarium 1 family, which consumed the most food (reference Table 2.21).

Table 2.21. P13 Group Total Food Consumption during Flight

Experiment Group	Total Food (g)
Flight, litter 1	1661.0
Flight, litter 2	1753.0
Vivarium, litter 1	1903.9
Vivarium, litter 2	1695.1
Sim-Caged, litter 1	1693.4
Sim-Caged, litter 2	1602.5

Water —

P7: Due to the reorganization of the neonates inflight, accurate water consumption data per litter in the P7 group could not be calculated.

P13: Water consumption data could not be calculated as an inflight refill was performed in the AEM and the amount of delivered water was not recorded.

2.3.2 Mammalian Development Experiments

Baldwin, Kenneth M. ***Neural-Thyroid Interaction on Skeletal Isomyosin Expression in 0 G* —**

Objectives: The objective of this experiment was to examine the interactive roles of gravity, innervation, and thyroid hormone (T3) in the developmental programming of myosin heavy chain (MHC) isoform expression in neonatal rodent antigravity and locomotor skeletal muscle. The central hypothesis tested is that gravity exerts a profound influence on the development and maintenance of slow (Type I) MHC expression in antigravity and locomotor muscle, such that in its absence, a significant number of muscle cells up-regulate the expression

of fast MHCs due to an increased responsiveness to thyroid hormone. In contrast, the normal expression of the fast IIx and IIb MHCs are developmentally regulated independently of gravity, but require both the presence of an intact nerve and T3 in order for these isoforms to reach full maturation in expression by replacing neonatal/embryonic MHC isoforms that are normally only expressed during fetal and early neonatal development. An additional objective is to determine whether muscle development, in the absence of gravity, creates a deleterious response, whereby recovery from exposure to microgravity in the neonatal stage results in an irreversible effect on muscle mass and the pattern of adult myosin isoform expression.

Approach: Flight, Simulated Caged Controls, and Vivarium rodents were divided into two subgroups: normal and thyroid deficient (TD). At recovery, key muscles were removed to study MHC isoform expression at both the mRNA and protein level of analysis using electrophoretic, immunohistochemical, and *in situ* hybridization technology. Due to the loss of neonates during flight, tissue samples could not be obtained from animals allowed to recover for 30 days postflight, as originally planned.

Results: Body weights of both the normal (euthyroid) and TD flight rats were significantly lower than the counterpart ground-control groups. Data suggests that lack of nutrition cannot account for the lack of weight gain. Absolute muscle weights were also significantly reduced in all flight groups relative to age-matched ground controls. Both body weight and muscle weight was lower in the TD groups than in the euthyroid groups. In the anti-gravity slow-twitch soleus muscle, space flight caused a greater relative atrophy response than in their fast-twitch counterparts. When soleus data was normalized for body mass, it was shown that the relative muscle mass of the soleus did not increase as a result of space flight; it remained essentially the same as that seen at seven days of age. Space flight also blunted slow MHC gene expression in the developing soleus muscle and created a profile typically seen in most fast muscles. In contrast, in the TD animals, expression of the Type I MHC was essentially augmented along with retention of small amounts of both the embryonic and neonatal MHCs in both the flight-based and ground-based groups relative to what is typically seen in euthyroid animals during normal development in 1 G. Non-weight-bearing leg muscles such as the tibialis anterior appeared to be the least affected by space flight.

Kosik, Kenneth S. ***Neuronal Development under Conditions of Space Flight —***

Objectives: Considerable development of the hippocampus occurs in rats after birth. Therefore, the hippocampus, which is required for spatial learning, is more likely to be affected by microgravity exposure at a young age. This experiment examined the hypothesis that exposure of rat neonates to microgravity will result in altered activity that will lead to altered development. This study evaluated the cognitive mapping abilities of rats that spent part of their early development in a microgravity environment. Another objective of this experiment was to analyze neuronal morphology and determine the synaptic functional plasticity in the developing nervous system of rat neonates raised in microgravity. Finally an analysis of the distribution of specific protein components of the nervous system was conducted, with particular emphasis on the cytoskeletal synaptic proteins, in rat neonates raised in microgravity.

Approach: Litters of male and female Sprague-Dawley rat pups were launched into space aboard the NASA Space Shuttle Columbia on either post-natal day 8 (P8) or 14 (P14), and remained in space for 16 days. These animals were designated as flight (FLT) groups. Two age-matched control groups remained on Earth: those in standard vivarium housing (VIV) and those in identical housing to that aboard the Shuttle (SIM, Simulated Caged Control). Upon return to

Earth, all animals were tested in three different tasks, the Morris water maze (MWM), a modified version of the radial arm maze (RAM), and an open field apparatus (OFA), to measure general activity and exploratory activity. Performance and search strategies were evaluated in each of these tasks using an automated tracking system (Poly-Track, San Diego Instruments). The analysis of the hippocampus included a determination of dendritic extents, a quantitative analysis of the synaptic structure and spinal architecture, an analysis of isoform expression of specific cytoskeletal and synaptic proteins, and a determination of the onset of long-term potentiation.

Results: There were remarkably few differences between the FLT groups and their earth-bound controls in these tasks. FLT animals learned the MWM and RAM as quickly as controls. Evaluation of search patterns suggested subtle differences in patterns of exploration and in the strategies used to solve the tasks, but these differences normalized rapidly. Together, these data suggest that development in an environment without gravity has minimal long-term impact on cognitive mapping. Any differences due to development in microgravity quickly reversed after return to Earth normal gravity.

Nowakowski, Richard S. ***Reduced Gravity: Effects in the Developing Nervous System —***

Objectives: The central nervous system (CNS) is the single most complicated organ of the body and its normal development is the consequence of a complex series of events such as cell proliferation, migration, and differentiation. In the developing CNS of mammals, these fundamental events occur for the most part in separate compartments, lending the system to detailed study. The objective of these experiments was to determine the short-term and intermediate-term physiological effects of microgravity on the cells of the developing CNS, in particular by examining cell proliferation, the movement of nuclei of the cells during the phases of the cell cycle, and neuronal migration. Although the primary goal of the investigation was to assess cell proliferation and neuronal migration in the developing brain of fetal (prenatal) mice, there were two secondary goals: to assay cell proliferation in the adult tissue and also to assay cell proliferation in a second brain region at a later stage of development. Thus, tissues (i.e., skin and gut) were also collected from the dams to assess cell proliferation in adult mice. In addition, cell proliferation as assessed by cerebellar foliation was evaluated in tissue obtained from postnatal rats that were the primary experimental animals of other members of the Mammalian Development team.

Approach: This study used fetal mice to examine the short-term and intermediate-term effects of space flight and reduced gravity on the cells of the developing CNS. Numerous preflight ground experiments were performed to develop the procedures and background data needed for the flight operations and for the interpretation of the flight data. For the flight experiment, timed-pregnant mice were launched at embryonic (E) days E8, E10, and E12. Two markers of cell proliferation, bromodeoxyuridine (BUdR, which is detected immunohisto-chemically) and tritiated thymidine (3H-thymidine, which is detected autoradiographically) were used to track cell proliferation and migration. The markers were administered by intraperitoneal injection to pregnant mice on FD 3 and FD 6. Twelve of the 18 mice were euthanized approximately 2.5 hours after the injection of the first marker. The fetuses were removed for analysis of short-term effects. The remaining six mice were euthanized approximately three days after the injection of the first marker, and the fetuses were removed for analysis of intermediate-term effects. Tissue received from other PIs was embedded in paraffin for routine histological processing and analysis.

Results: Combined flight and control groups contained >90% pregnant mice as a result of the preflight animal selection procedure; thus, this procedure greatly enhanced the success of the experiment. The pregnancy rates were well within the planned guidelines, and all six of the planned experiments were completed successfully. At this time data is available from four of the six experiments. (The results presented here are from the cell proliferation groups.) After two or five days in the microgravity environment, the following results were obtained: (1) The height of the ventricular zone is greater in the Flight animals than in either control group. (2) Flight animals have a greater number of nuclei per unit of ventricular surface than either control group. (3) Flight animals have a greater number of labeled nuclei per unit of ventricular surface than either control group. (4) In the Flight group the ratio of cells labeled with ^{3}H-TdR to those labeled with BUdR in the proliferative zone in a 300 um extent along the ventricular surface is significantly greater than in either control group. (5) Differences in relative maturity and labeling characteristics suggest that the housing conditions provided by the AEM have an impact on fetal development. Although housing conditions in the AEM appear to have contributed to some of the observed differences, that contribution is insufficient to account for the significant differences observed in the Flight group in the number of ^{3}H-TdR-only labeled nuclei OR the total number of cells.

The most parsimonious interpretation of the available observations is two-fold. (Further work is necessary to distinguish between these two possibilities): a) that ^{3}H-TdR uptake and/or incorporation into DNA to detectable levels is more rapid in the Flight group and/or b) G2 + M is shorter, and more labeled cells have completed M phase in the Flight group during the period of the experiment.

A key observation (5 in the above list) in the data available thus far is that the proportion of cells labeled with ^{3}H-TdR is greater in the flight group than in either of the control groups. This finding is significant because it means that a basic cellular property, either cell cycle or nucleotide metabolism, both of which are common to all cells in all organisms, is modified during space flight. To be accepted as accounting for the data collected so far, these findings will need to be corroborated by replication on future space flights.

An additional key observation is that the interkinetic nuclear migration of the labeled cells is affected in the flight group. The data indicates either that the movement towards the ventricular surface is slower or delayed. This finding is significant because this movement is mediated by the cytoskeleton and thus indicates that another basic cellular property, perhaps cytoskeletal assembly/disassembly is modified during space flight. These findings will also need to be corroborated by replication on future space flights.

Raymond, Jacqueline. ***Microgravity and Development of Vestibular Circuits —***

Objectives: Exposure of the vertebrate inner ear to microgravity has been shown to result in an alteration of the gravity receptors of the vestibular system as well as vestibular sensory-motor rearrangement. If this exposure is experienced as an adult, the effect is temporary and reverses upon return to 1 G. In contrast, it is hypothesized that if such structural modifications occur during the developmental period, they may induce permanent changes in the vestibular sensorineuronal circuits. This experiment investigated the vestibular system at the level of the gravity receptors (sensory hair cells) and the primary neurons relaying the sensory signals (the vestibular neurons) and their potential plasticity at the structural and biochemical levels. Structures not involved in gravity detection (the cochlea and cochlear nuclei) were used as a control.

Approach: Inflight tissue samples were collected as part of the integrated neonate perfusions and dissections on FD 8 and FD 15. Postflight samples were collected eight hours after landing. Vestibular receptors were dissected out in cold phosphate buffer solution (PBS). For Vibratome sectioning, the ampullar cristae and utricular and saccular maculae were separately embedded in 4% agarose in PBS and cut into 50 μm sections with a Vibratome. For cryostat sectioning, the receptors were incubated overnight at 4 °C in 30% sucrose in PBS and cut into 14 μm sections. Vibratome sections were prepared for immunofluorescent microscopy by incubation with varied primary and secondary antibodies. Some samples were double-stained using different combinations of poly- and monoclonal antibodies applied simultaneously. Brainstems were sectioned and prepared for immunofluorescent microscopy with similar procedures. Immunostained sections were analyzed with a BioRad-MRC 1024 laser scanning confocal microscope.

Results: Preliminary observations did not indicate a significant reorganization of the macular sensory organs, or their afferent and efferent connections. Expression of parvalbumin, calretinin, and calbindin were unaffected. Sensory cells and their afferent fiber distribution, as well as the distribution of synaptic proteins, remained unchanged in flight animals. This lack of effect on the organization of the maculae and ganglion may indicate that the peripheral otolithic organs and their afferent networks are less sensitive to environmental changes than the integrative structures of the brain. Another possible explanation is that the critical periods of development for these peripheral organs occur at an earlier age than post-natal day 8. Peripheral nerve processes of the efferent system appeared to develop and mature normally inflight. It is not known whether the lack of a detectable effect of microgravity is due to the parameter analyzed; ultrastructural observations should be done for clarification. Microgravity exposure did impair the development of vestibular neurons and Purkinje cell axonal branching in the vestibular nuclei. However, it is not clear if this implies delayed development or a definitive failure resulting from microgravity exposure during a critical period of development.

Riley, Danny A. ***The Effects of Microgravity on Neuromuscular Development* —**

Objectives: Previous research has indicated that a critical period of weightbearing may exist for the development of the motor system in animals. If this is the case, there are striking implications for raising normal animals, including humans, in the microgravity environment of space. This experiment tested the hypothesis that gravity-associated weightbearing is required postnatally for normal neuromuscular development of motor neurons, neuromuscular junctions, and muscle fiber types of the antigravity soleus muscle, but not for that of the extensor digitorum longus (EDL), a nonweightbearing muscle.

Approach: Rat pups, eight days old at launch, were exposed to microgravity during 16 days of their development. Because of high inflight mortality among the pups, specific studies of the development of soleus and EDL motor neurons and assessment of long-term recovery changes in the neuromuscular system could not be fully completed. The study focused on fiber-type differentiation and neuromuscular junction development. Muscle and spinal cord tissues of Neurolab rats were processed and analyzed to evaluate muscle fiber type differentiation, cytoplasm/nucleus ratios, neuromuscular junction development, and spinal motor properties. A ground-control simulation, consisting of a group of hindlimb-suspended pups with a schedule of four hours unloaded and two hours returned to the dam for nursing, was repeated 24 hours a day for nine days. Littermates of the hindlimb-suspension control were removed from the dam on the same schedule as the unloaded rats and singly housed to provide isolation controls. The data from

the ground controls were used to distinguish unloading effects from isolation effects on neuromuscular system development.

Results: Exposure to space flight resulted in microgravity-induced unloading as well as reduced neonate-dam and neonate-neonate interactions. The inflight retardation of neonate body weight gain was recovered one month postflight. Fewer large soleus fibers postflight suggested stunted growth for some fibers. Higher cytoplasm/nuclear ratios indicated a persistent deficit in soleus myoblast function. Differentiation from embryonic to slow fiber type was transiently retarded and enhanced toward fast type. Space flight temporarily increased the susceptibility of developing soleus fibers to reloading damage. Elimination of multiple innervation was completed during space flight. The pattern of terminal branching of motor nerve endings was less complex, implying delayed maturation. Space flight retarded the growth of spinal motor neurons. Down-regulation of mitochondrial cytochrome oxidase activity and gene expression in lumbar spinal motor neurons indicated lower oxidative capacity in the flight rats. Lower levels of choline acetyltransferase and Cat-301 proteoglycan indicated delayed motor neuron maturation, regarding neurotransmitter synthesis and extracellular matrix organization. Overall, the results from the neonates emphasize the importance of weightbearing exercise for the normal development of the infant neuromuscular system.

Shimizu, Tsuyoshi. ***Development of the Aortic Baroreflex under Conditions of Microgravity —***

Objectives: It is possible that the mechanical behavior of the baroreceptor region of the aortic arch may be changed, or a resetting of the baroreceptor response may occur, when mammals are exposed to chronic microgravity. The purpose of this study was to examine the effects of microgravity on the structural and functional development of the aortic baroreflex, a neural control system for blood pressure. The experiment objectives were to observe and analyze the effect of microgravity on the baroreflex responses and on the fine structure of the aortic nerves, which are the afferent pathways of the aortic baroreflex, in growing rats raised in space.

Approach: Six 9-day-old rat neonates raised for 16 days in space were selected for physiological and histological examinations on the day of landing (Recovery + 0 days = R+0), and another six neonates were reserved for experiments on 30 days postflight (R+30). Following administration of anesthesia, blood pressure, heart rate and aortic nerve activity were recorded, and baroreflex tests were pharmacologically performed. The animal body was perfused with a fixative and tissues were prepared for electron and light microscopy analysis. Reological properties of the aorta extirpated on R+0 were also observed.

Results: Flight pups (FLT) had significantly lower body weights than the Simulated Caged Control (SIM) and Vivarium (VIV) ground controls, but there were no significant correlations between body weight and other parameters examined. The FLT group initially had difficulty walking, and the tip of the tail in most was slightly necrotic. Two FLT pups could not be used for baroreflex tests because of very low blood pressure observed on R+0.

Differences in blood pressure and heart rate seen at R+0 between the FLT and control groups dissipated by R+30. Each parameter of blood pressure, including mean blood pressure (MBP), systolic blood pressure, and diastolic blood pressure (DBP), was lower in the FLT group than either the SIM and VIV groups at R+0, though there was no significant difference between FLT and control groups at R+30. Blood pressure in the R+30 FLT group was significantly higher than that measured on R+0. Similarly, basal heart rate (HR) at R+0 was higher in the FLT group than in the control groups, though there was no significant difference between FLT and SIM. On R+30

all three groups showed lower HR than at R+0 with no significant differences between both VIV groups.

Baroreceptor reflexes behaved similarly. On R+0 the index of baroreceptor reflex sensitivity (delta HR%/ delta MBP%) showed significant differences between the FLT and SIM group, with the FLT pups having the lowest value. At R+30 there was no significant index differences between the three groups. Afferent sensitivity in the aortic baroreceptor reflex was also decreased in the FLT group on R+0, and again differences were not seen between any groups at R+30.

Structural changes in the aortic nerves and wall appeared more fixed. Due to structural and technical problems, samples of aortic nerve available for electron microscopic analysis were extremely limited. On R+0, the numbers of unmyelinated fibers and the ratio of unmyelinated to all other fibers were significantly less in the FLT group than in the controls, and these differences were still observed at R+30. Aortic wall tension produced by strain was significantly smaller in FLT than in both control groups on R+0. The thickness of the aortic walls in FLT pups was about 70% of those in the other groups; the amount of smooth muscle cells and fine elastin fibers were markedly reduced.

In conclusion, the space environment, probably its microgravity component, affects development of the aortic baroreflex system and autonomic regulation of the blood circulation. However, the function of the baroreflex system can develop normally and adapt to the earth environment of 1 G if the animal returns during its developing stage; although, there is a possibility that the structural differences of the afferent pathway may be permanent.

Walton, Kerry D. ***Effects of Gravity on Postnatal Motor Development —***

Objectives: The force of gravity is one of the few constant factors during the evolution of the nervous system and is deeply embedded in its functionality. An animal's posture is dependent on the appropriate force being maintained at every joint of the skeleton in order to counteract the force of gravity. This experiment examines the adaptability of the motor nervous system to environmental demands. Since young animals are particularly susceptible to changes in their environment, they offer a sensitive model for nervous system plasticity. The hypothesis tested in this experiment is: 1) a normal gravitational field is essential for the normal postnatal development of the motor system; 2) elimination of weight-bearing will lead to profound changes in motor system organization; 3) changes in motor function will be most marked when animals are exposed to microgravity during sensitive periods of development; and 4) functional changes will persist into adulthood when animals are exposed during critical periods of motor development.

Approach: Rat pup ages at flight allowed exposure to microgravity during both the sensitive period (P8-P24) and critical period (P14-P30) of neuromotor development. Inflight experiments evaluated locomotion, complex motor skills, and vestibular reflexes with the use of an Animal Walking Apparatus (AWA). Animals were videotaped inflight using two cameras simultaneously while they progressed along rods of varying diameters, along a 1/2-inch mesh surface, on a foam surface, and during tests of surface (or contact) righting. Postflight, animals underwent numerous non-invasive behavioral tests to test their motor skills including, swimming, walking, startle reflex and surface righting.

Results: Three general observations were made over the course of the experiment: (1) The exact set of movements used to achieve a goal, i.e., motor tactics, is influenced by the physical environment during development. This was found in both swimming and walking. Other

aspects of movement, such as how fast the movement is made, are not as sensitive. (2) The age of the animals influenced the magnitude and duration of the effect. For example, locomotion was more affected in the older than in the younger animals. However, the immaturity of surface righting tactics were more marked in the younger animals. (3) The length of time an animal spends in an altered environment determines if the effects will be transient or long lasting. Locomotion in the microgravity environment was dominated by the forelimbs; when the hind limbs were used, overstepping was observed. In addition, poor interlimb coordination was observed in these animals. Anatomical studies found that the arborization of the dendritic tree of cervial motorneurons is less rich in flight animals on the day of landing. Studies in the cerebral cortex have found differences on the day of landing that persist for at least three months post-flight.

A preliminary analysis indicates that an Earth-normal gravitational field is needed for the normal postnatal development of motor function. The tactics an animal used to achieve its motor goal, such as turning over, walking, or swimming are influenced by the environment. Thus, animals spending 16-days in microgravity use a different set of tactics to achieve their goal than ground-based control animals. In the case of surface righting, which did not occur in microgravity, the tactics for turning over were identical at launch and landing. This indicates that the postnatal development of motor skills requires activity in an environment context. Thus, postnatal development of motor skills represents a 'tuning' of the nervous system to the environment. Further, the anatomical substrates for this tuning are at the level of the spinal cord and cerebral cortex.

2.4 Aquatic Team

The Aquatic team (AT) studied how the vestibular system adjusts to microgravity. The experiments focused on the development and functioning of the gravity-sensing (vestibular) system in snails and fish. AT investigators and experiments are listed in Table 2.22.

Table 2.22. Aquatic Team Investigators and Experiments

Investigator	Experiment #	Experiment Title
Stephen M. Highstein Washington University School of Medicine, St. Louis	E088	Chronic Recording of Otolith Nerves in Microgravity
Michael L. Wiederhold University of Texas Health Center, San Antonio	E004	Development of Vestibular Organs in Microgravity

AT experiments used toadfish, snails, swordtail fish, and hornweed (reference Table 2.23 for experiments and controls associated with each animal group). The toadfish underwent surgery at the PI lab preflight to allow the insertion of an electrode into the vestibular nerve and attachment of an infrared telemetry transmitter. Two types of electrode implants were used: a wafer-type implant and a more traditional microwire electrode. Each fish received only one type of implant. During the preflight period at KSC, a second surgery was performed to install a pedestal required for fish implanted with the wafer-type electrode.

Table 2.23. Aquatic Team Animal Groups and Controls

Animal Group	# of Experiments Supported	Controls
Toadfish (*Opsanus tau*): 4 animals (housed in the Vestibular Function Experiment Unit)	1	Each animal served as its own control; baseline data was collected preflight.
4 adult and 200 juvenile swordtail fish (*Xiphophorus helleri*); 35 adult snails (*Biomphalaria glabrata)*; hornweed (*Ceratophylum demersum)* (maintained together in the CEBAS hardware)	1	Identical CEBAS unit

Toadfish were housed in the Vestibular Function Experiment Unit (VFEU), and the snails and swordtail fish were housed in the Closed Equilibrated Biological Aquatic System (CEBAS). The VFEU and CEBAS provided all life-support functions for the animals. Reference 3.2.3 (CEBAS) and 3.2.11 (VFEU) in the Hardware section for a description of these hardware items.

2.4.1 Aquatic Project Data

CEBAS Data (Snails, Swordtail Fish, and Hornweed) — ARC ground science personnel collected data on environmental conditions in the CEBAS module, as well as general health data for the experiment subjects. Data were collected from both flight subjects and 5-day delayed ground control subjects, housed in an identical CEBAS module. Parameters were measured preflight and postflight (L+16).

CEBAS Water Parameters: Postflight water analysis showed a non-ideal water quality in both the flight and ground CEBAS units after a 16-day duration (reference Table 2.24).

Table 2.24. CEBAS Flight and Ground Control Water Parameters

Parameter	L-2 (Flight)	L-2 (5-day Delayed Ground Control)	L+16 (Flight)	L+16 (5-day Delayed Ground Control)
NO_3^- (mg/l)	18	18	35	38
NO_2^- (mg/l)	0.062	0.050	0.027	0.181
NH_4^+ (mg/l)	0.029	0.043	0.166	0.176
P (mg/l)	0.102	0.154	0.459	0.331
Cl^- (mg/l)	4.27	4.51	0.98	1.62
Ca^{++} (mg/l)	30	130	200	222.92
pH	7.2	7.2	8.8	8.4
Conductancy (µS)	276	286	952	987
Total Hardness (dh)	10	10	38.5	25

Snail General Data: The spawn packs did not develop nominally inflight. It appeared that they developed either more slowly or stopped developing all together (reference Table 2.25). The cause of this has not been determined.

Both space-reared and ground-control snails lost their preference for downward-directed crawling during flight, and gradually re-acquired it over four days after landing. The cause of this has not been determined.

Table 2.25. Snail General Data

Parameter	L-5 (Flight)	L-5 (5-day Delayed Ground Control)	L+16 (Flight)	L+16 (5-day Delayed Ground Control)
Number of Adults	38	38	27	28
Survival Rate (%)	-	-	71.1	73.7
Weight of Adults (g)	-	-	11.6	12.8
Number of Neonates	30	30	207	155
Number of Spawn Packs	-	-	12	13
Spawn Packs on Video	-	-	12	11

Project data on snail statoconia volume and number were also collected (reference Table 2.26). The groups showed an average 30% increase in total statoconia volume. For the preparations of isolated statoconia, the data indicate that the increase in total volume is due to an increase in the number of statoconia, not in their individual sizes.

Table 2.26. Snail Statoconia Data

Snail Diameter	Day Fixed	Total Stone Volume Ratio: Flight to Ground
1 mm	R+0	1.43
1.5 mm	R+0	1.23
1.5 mm	R+5	1.20*
2.0 mm	R+0	0.95
2.0 mm	R+5	1.38*
1 mm	R+0	1.33*
1.5 mm	R+0	1.22*
2.0 mm	R+5	1.39*

* = $p < 0.05$

Hornweed General Data: *C. demersum* biomass increase was similar for microgravity and ground control CEBAS modules (reference Table 2.27).

Table 2.27. Hornweed Flight and Ground Control Weight and Biomass

Parameter	L-5 (Flight)	L-5 (5-day Delayed Ground Control)	L+16 (Flight)	L+16 (5-day Delayed Ground Control)
Weight (g)	49.97	49.8	119.1	115.5
Biomass Increase (%)	-	-	238.3	231.8
Algae (g)	nd	nd	nd	very few

Swordtail Fish Adult General Data: Weights of flight and ground control animals were taken preflight and postflight. (reference Table 2.28).

Table 2.28. Swordtail Fish Adult Flight and Ground Control Weights

Female Weight (g)	L-7 (Flight)	L-7 (5-day Delayed Ground Control)	L+16 (Flight)	L+16 (5-day Delayed Ground Control)
Fish #1	2.02	1.48	1.96	1.43
Fish #2	1.71	1.59	1.41	1.64
Fish #3	1.72	1.22	1.78	-
Fish #4	1.56	1.71	1.31	-
Total Weight	7.01	6.00	6.46	3.07
Average Weight	1.75	1.50	1.61	1.54
Standard Deviation	0.19	0.21	0.31	0.14

Swordtail Fish Juvenile (Born L-9 to L-7) General Data: Juveniles were housed in the housing proper and a smaller number were housed in the filter area. Table 2.29 presents the data separately to maintain the distinction of where the juvenile swordtail fish were housed in the CEBAS module. The data demonstrate the ground controls had a higher survival rate than did flight animals.

Table 2.29. Swordtail Fish Juvenile Flight and Ground Control Parameters

Parameter	L-3 (Flight)	L-3 (5-day Delayed Ground Control)	L+16 (Flight)	L+16 (5-day Delayed Ground Control)
Average Number*	200	200	23	48
Survival Rate (%)*	-	-	11.5	24
Average Weight (mg)*	13.74	15.37	14.96	16.86
Standard Deviation (mg)*	2.19	1.78	2.52	2.94
Average Number**	25	25	2	11
Survival Rate (%)**	-	-	8	44
Average Weight (mg)**	13.74	15.37	-	13.10
Standard Deviation (mg)**	2.19	1.78	-	2.81

* Neonate Tank ** Filter

VFEU Data (Toadfish) — ARC ground science personnel collected data on water quality in the VFEU, as well as on the general health of the toadfish. Animals numbered #2 and #3 were found to be in excellent health at landing, though animal #3 showed superficial necrosis at the transmitter implant site. Animals numbered #1 and #4 were found dead upon landing. Water was analyzed (reference Tables 2.30–2.33 and Attachment 3), but no correlation between water quality and animal health could be made. The large increase in nitrogenous compounds in the dead animals' Fish Packages was thought to be a result of decomposition and not necessarily responsible for the cause of death.

Table 2.30. Water Quality in Fish Package 1

	pH	NH_4-N (mg/L)	NO2-N (mg/L)	NO3-N (mg/L)
Preflight	8.1	< 0.1	< 0.1	5.6
FD 3	7.8	< 0.1	< 0.1	26
FD 6	7.9	0.5	< 0.1	37
FD 9	7.7	0.3	< 0.1	41
FD 12	7.7	0.9	< 0.1	46
FD 15	7.8	14.0	0.2	53
Postflight	8.0	51.4	1.2	58

Table 2.31. Water Quality in Fish Package 2

	pH	NH_4-N (mg/L)	NO2-N (mg/L)	NO3-N (mg/L)
Preflight	8.1	< 0.1	< 0.1	4.8
FD 3	7.8	< 0.1	< 0.1	10
FD 6	7.9	< 0.1	< 0.1	12
FD 9	7.8	1.5	< 0.1	14
FD 12	7.8	0.2	< 0.1	16
FD 15	7.8	1.1	< 0.1	23
Postflight	7.7	7.8	< 0.1	27

Table 2.32. Water Quality in Fish Package 3

	pH	NH_4-N (mg/L)	NO2-N (mg/L)	NO3-N (mg/L)
Preflight	8.1	< 0.1	< 0.1	4.2
FD 3	7.9	< 0.1	< 0.1	12
FD 6	7.9	1.2	< 0.1	16
FD 9	7.9	0.2	< 0.1	18
FD 12	7.9	0.6	< 0.1	21
FD 15	7.8	0.8	< 0.1	24
Postflight	7.7	2.8	< 0.1	26

Table 2.33. Water Quality in Fish Package 4

	pH	NH_4-N (mg/L)	NO2-N (mg/L)	NO3-N (mg/L)
Preflight	8.2	< 0.1	< 0.1	4.2
FD 3	7.9	< 0.1	< 0.1	9.6
FD 6	7.9	< 0.1	< 0.1	11
FD 9	7.9	0.9	< 0.1	16
FD 12	7.9	8.7	0.1	22
FD 15	7.9	38.6	< 0.1	26
Postflight	7.8	61.7	0.3	27

2.4.2 Aquatic Experiments

Highstein, Stephen M. ***Chronic Recording of Otolith Nerves in Microgravity —***

Objectives: The main goals of this study were to record the responses of primary afferents of the otolithic organs to document otolithic organ response dynamics in normal gravity and in microgravity. According to the Otolith Asymmetry Theory, structural asymmetries between the bilateral otolithic organs develop during growth and maturation. However, in 1 G, Central Nervous System efferent neural impulses compensate for the asymmetries by adjusting primary afferent discharge to be equivalent bilaterally. When the organism is exposed to an altered gravitational environment, the existing structural otolithic asymmetries become evident as the efferent compensation is now inadequate. Thus, unbalanced signals are transmitted to the brain. Studies of these aspects of the vestibular system and its efferent control can add to our knowledge of its function and may suggest future therapies for control of Earth-bound motion sickness.

Approach: Experimental difficulties precluded obtaining useful in-flight data as originally planned. However, fish were received within eight hours of the Shuttle return to Earth and utricular nerve afferents recorded sequentially for five days postflight. For this, anesthetized, paralyzed toadfish underwent a small craniotomy to allow the implantation of glass micro-electrodes (2 M $LiCl_2$), in the nerves innervating the utricle. Records of primary afferents in response to linear acceleration were taken. Position and motion of the fish were documented by linear and rotary potentiometers.

Results: Results from Neurolab were combined with those from STS-95, for a total of four experimental subjects. Control responses were obtained from three fish that did not fly. For flight subjects, the magnitude of response to an applied linear acceleration was on average three times greater than for controls within the first day postflight. By 30 hours post flight, responses had returned to normal and were statistically similar to controls. Directional selectivity appeared unaffected by exposure to microgravity. To examine for possible recording bias, all measured parameters were compared between control and post flight afferents; no statistical difference was

found in the range and mean of afferent discharge rate and regularity of discharge between postflight and control fish. Thus the reduced gravitational vector and linear acceleration in orbit apparently resulted in an up-regulation of the sensitivity of utricular afferents. More tests must be done to determine whether a specific population of afferents demonstrated increased sensitivity or whether this finding is a general feature of all classes of cells.

The original plan called for the implementation and perfection of a sieve electrode to allow for continuous recording of afferents during flight. For this the sieve was placed in the path of a severed utricular nerve and the nerve allowed to regenerate through the sieve. Previous work from our laboratory documented the time course and completeness of nerve regeneration in the species employed. Presently although experimental difficulties precluded the completion of the entire original plan, the perfection and utilization of the sieve electrode was achieved. High fidelity records of primary otolithic nerve single afferents were recorded chronically. This sieve technology might have future application to the human condition in conjunction with the utilization of prosthetic devices or other prostheses that require an interface with the nervous system.

Wiederhold, Michael L. ***Development of Vestibular Organs in Microgravity —***

Objectives: Many species sense gravity, and therefore linear acceleration, by way of otoliths (dense calcium carbonate crystals attached to hair cells and associated nerve fibers). As the mass moves with acceleration, a signal is sent through each hair cell to the central nervous system. The knowledge of the factors that control development of these otoliths (and their analogs in some species) is limited. Previous studies suggest that altered gravity does not substantially affect the volume of the otoliths or their analogs in adult animals. This study was designed to test the hypothesis that during development the mass of the otolith is regulated to achieve a desired weight; as such, one would expect to reference larger-than-normal otoliths in animals reared in microgravity.

Approach: The statoconia (analogous to otoliths) of the pond snail, *Biomphalaria glabrata*, and the otoliths of the swordtail fish, *Xiphophorus helleri*, were the focus of this study. Thirty-five adult snails, four pre-mated adult female swordtail fish, and 50 to 200 juvenile swordtail fish were flown in the Closed Equilibrated Biological Aquatic System (CEBAS), which contained seven liters of water and 50 grams of the hornweed, *Ceratophylum*. The specimen container was videotaped for later analysis. Many of the snails mated in flight, and produced the juvenile snails used in the experimental analysis. The pregnant adult swordtail fish were selected at a stage that they would produce developing fry but not have any hatch by the end of the mission. On landing day, approximately half the juvenile snails were fixed; the other half were fixed five days postflight. Adult fish ovaries and juvenile fish were fixed in alcohol on landing day. Fixed snails were removed from their shell and sectioned at 1-2 μm; serial sections were examined by transmission electron microscopy.

Results: Results were obtained from both the Neurolab flight (16-day) and a similar experiment of nine days duration, using the same organisms, flown on STS-89. Total statoconia volume in the snails varied considerably within both the flight and ground control groups. However, the difference in mean values for the two groups was significant at $p < 0.05$, with the average total volume greater in the flight group. In most of the groups of flight snails (divided into groups by shell diameter), the increase in statoconia volume increased as the animals developed another five days on Earth. Overall, the flight-reared snails had approximately 50 percent more statoconia than the ground controls. This indicated that rearing in microgravity

causes the supporting cells to produce more statoconia, of approximately the same size as in ground-reared animals.

Otoliths of the embryonic fish from STS-90 (Neurolab) exhibited a greater growth, with increased body length in the flight-reared animals, compared to ground controls. Although there was a trend for larger otoliths in the flight-reared juvenile swordtails, this difference did not reach statistical significance. The embryos from STS-89 were much smaller that those retrieved after STS-90, since this was a shorter mission. In this case, the growth of otoliths of the ground-reared fish embryos was actually larger than that of the flight-reared animals. These results suggest a critical period, in the late embryonic stages, where rearing in microgravity produces larger otoliths.

2.5 Neurobiology Team

The Neurobiology (NB) team concerned itself with the question of what amount of normal development is genetic and how much depends on cues from the environment. The NB team consisted of one experiment (reference Table 2.33).

Table 2.34. Neurobiology Team Experiment and Investigator

Investigator	Experiment #	Experiment Title
Eberhard R. Horn University of Ulm, Germany	E089	Development of an Insect Gravity Sensory System in Space

The NB team experiment used crickets as experiment subjects (reference Table 2.35 for the associated controls). The crickets were housed in the BOTEX incubator, which provided all life-support functions for the animals. Reference 3.2.2 in the Hardware section for a description of the BOTEX.

Table 2.35. Neurobiology Team Animal Group and Controls

Animal Group	# of Experiments Supported	Controls
Crickets (*Acheta domesticus*): Eggs, 1st, 4th, and 6th stage larvae.	1	Inflight reference (1 G) control. Hypergravity synchronous control (3 G).

2.5.1 Neurobiology Project Data

ARC did not collect any project data specific to the neurobiology experiment. Insect maintenance housing and selection were coordinated by the investigator and his team.

2.5.2 Neurobiology Experiment

Horn, Eberhard R. ***Development of an Insect Gravity Sensory System in Space —***

Objectives: The objective of the CRISP (Crickets in Space) experiment was to examine to what extent genetics or environmental factors affect the development of a neuronal sensory system. The question under investigation was whether irreversible anatomical and physiological changes in sensory, neuronal, and motor systems could be induced by periods of altered environmental conditions during early development. Crickets provide an excellent model system

for neurobiology experiments. They possess external gravity receptors located on their abdominal cerci, which can regenerate morphologically and functionally if lost during postembryonal development. Neural information generated from the stimulation of these receptors is transmitted by way of a single interneuron called the position sensitive interneuron (PSI), the activity of which relates to the posture of the animal's body. The CRISP experiment tested the functionality of this neural system in crickets raised without normal gravitational cues.

Approach: Cricket eggs and 1st, 4th, and 6th stage larvae were flown on Neurolab in the BOTEX incubator. The use of four age groups allowed for comparison of adaptation to microgravity between nervous systems in differing stages of development. Lesions of the gravity sensory system were performed on 6th stage larvae. A 1-G inflight control (on the BOTEX reference centrifuge) and a 3-G hypergravity control were performed for the four larval stages. Postflight, cricket roll-induced compensatory head response (rCHR) was videotaped and analyzed for the flight and control groups. Recordings of PSI activity were taken and compared between 1) flight and ground groups, and 2) intact and regenerated cerci.

Results: Eggs hatched and larvae developed peripheral and central gravity-sensing structures in spite of the altered gravitational cues. Larvae that had undergone lesions of the cerci were able to successfully regenerate the organs in microgravity as on the ground. Postflight, larvae demonstrated normal walking behavior. Significant behavioral differences in the rCHR were not observed between lesioned and intact larvae in either the flight or the ground samples. Larvae which hatched in orbit showed a retardation of 1-G re-adaptation. The PSI showed a significant sensitivity to microgravity exposure, contrasting with the behavioral analysis. A sensitivity was also seen in the 3-G hypergravity but only during the period of 1-G re-adaptation. Overall, the study indicates that the physiology of an identified gravity-sensitive neuron is strongly affected by microgravity exposure while behavior of the larvae remains less or unaffected.

2.6 Lessons Learned

Many lessons learned accumulated during the Neurolab mission. Those that follow are based on how the science team viewed their involvement and that of other groups within the project. Most of these can be placed into three broad categories: scheduling, communications, and animal welfare. While the observations presented here can be considered single events, the recommendations that follow can easily encompass similar if not related events.

2.6.1 Communication

As with any large mission utilizing hundreds of scientists, ground support personnel, and project team members, some problems with communication flow were encountered.

1. Observation: As changes occurred with personnel leaving or being reassigned, communication fallouts were inevitable, which in turn caused delays in deliverables and procedure development.

Lesson Learned: Involvement and communication between Science, Engineering, and Operations should be continuous throughout the development of the payload. An initial visit of science, engineering, and operations representatives to the PI lab is an extremely valuable if not essential trip that should be planned in the future to ensure a thorough understanding of the investigator's objectives, but also to convey to the PI what the project needs from him or her.

2. Observation: Two experiments (Pompeiano and Fuller) received the wrong samples, which then had to be returned to the proper lab.

Lesson Learned: In spite of documentation and agreed-to protocols, the likelihood of human error in a project with this magnitude is always a possibility. In this instance, cross-checking shipping labels with sample packaging is a solution. But, for all tasks, it is important to double check, even using others to verify, and follow-through.

3. Observation: When working with foreign investigators to define requirements for the Logistics Integrated Requirements Document (LIRD), the language barrier and being physically separated made it difficult to define all the requirements.

Lesson Learned: If the project is to provide generic laboratory equipment to support the investigator's needs while the investigator is utilizing NASA-provided facilities, a site visit by the investigator and/or a laboratory representative to the NASA facility as well as a visit by NASA personnel to the investigator's lab is critical to establish laboratory requirements. This has special relevance if the investigator is an international partner. In addition, laboratory equipment catalogs should be provided to the investigators to provide commonality in descriptions required.

2.6.2 Scheduling

1. Observation: Problems arose from scheduling or finalizing integrated procedures before the individual component procedures had been fully developed.

Lesson Learned: When adapting a ground experiment for flight, it is important that the experiment be at a mature state. This allows for adequate consideration of crew safety concerns, containment issues, and experiment constraints derived from manned space flight requirements. But also as critical is detailing the ground activities that occur prior to flight and those occurring after the receipt of the flight experiment. Specific examples include:

- Test Operation Procedures (TOPs)—TOPs need to be written before the LIRD and the ground processing timeline are developed to fully define requirements prior to integration into the LIRD.
- Plans for use of radioactive materials — early planning is crucial for a smooth operational flow during actual flight and ground support operations.
- Methodologies for all aspects of the investigator's research intended for flight should be documented.
- The investigator should detail how the postflight analysis will be performed especially if they are to be performed at NASA facilities and require NASA involvement or resources.

2.6.3 Animal Welfare

1. Observation: Significant problems were encountered with rat neonate mortality of animals housed in the RAHF during Neurolab.

Lesson Learned: Various explanations for the increased neonate mortality have been offered, such as the inability of the neonates to locate the damn via olfactory or tactile cues in a weightless environment to the lack of surface features to allow for grasping behavior. While no definitive study has been performed to isolate the cause, it is clear from the data and observations collected

from the flight use of the AEM, that the AEM is a preferable habitat for neonates. One possible explanation for this may be due to the increased grasping surfaces provided by the cage design. Even though ground testing of dams and neonates in RAHF cages had been performed, it has been made evident by the events of the Neurolab flight that neonates and the associated behavior of nursing dams and neonates require further study in the space environment.

2. Observation: Difficult decisions had to be made on how to both preserve animal welfare for the surviving rodents and recover some of the expected science return.

Lesson Learned: While ground housing tests were performed in the flight article, with the flight complement of specimens of the appropriate age, weight, and size, and tested to the flight duration, the uniqueness of the space environment leads new challenges that are difficult to ascertain from just ground testing. Because of this, it is critical to consider worst-case "what-if" scenarios, establish risks, and develop sharing protocols that maximize the science than can be obtained should an event such as this occur.

3.0 Hardware

3.1 Introduction

NASA Code UL, Life and Microgravity Sciences, designed the Neurolab mission to utilize previously flown flight hardware from NASA and international partners to allow fast, low-cost payload development and support for the many experiments and funding by NASA, NIH, and partner international space agencies.

Code UL solicited previously flown flight hardware for the non-human portion of the payload from NASA ARC and partner international space agencies that together could support a wide range of biological research subjects. These hardware items were then described in a NASA Announcement of Opportunity released in 1993 to which investigators proposed experiments.

After the science was more fully defined and Shuttle resources (i.e. power, mass, and volume) were determined, it became apparent that fewer existing flight hardware items could be reused for the manifested experiments than previously considered. A decision was made that every effort would be made to fly the complement of selected experiments, even if hardware modifications were required. Hardware development for Neurolab also coincided with preparations for several small payload missions and ARC's involvement in the NASA-Mir program.

Extensive modification and refurbishment of the Research Animal Holding Facility was required to provide a habitat for the adult rats implanted for biotelemetry and to support the selection of experiments that required nursing dams with litters. There was a large development effort to provide an Advanced Animal Habitat (AAH) to fly for the first time on Neurolab. The AAH was considered to be the next generation of the Animal Enclosure Module, including upgraded features such as inflight access, water measurement, and inflight food changeout and replenishment. However, due to budget and schedule concerns, the AAH project was terminated and the AEM was used in its place.

The 17-day mission was regarded as an overall success. However, several hardware anomalies occurred inflight that warranted postflight investigation. A Hardware Failure Review Board (HFRB) was established to assess the inflight anomalies.

Anomalies and associated lessons learned are included below with the hardware descriptions and a listing of associated experiments for each item developed or modified for the ARC payload.

3.2 Hardware Overview

3.2.1 Animal Enclosure Module (AEM): Access Modifications

Reference Figure 3.1 for a drawing of the Animal Enclosure Module.

Four AEMs were flown on Neurolab in the Space Shuttle Middeck.

Description — For Neurolab, ARC engineers modified the Animal Enclosure Module (AEM) to provide on-orbit access to rodents and a means of transporting rodents from the AEM to the General Purpose Work Station (GPWS), located in the Spacelab, where experiment procedures

were conducted inflight. The access modifications provided particulate containment during all access and transfer operations.

The AEM Access modifications included five changes/additions to the basic AEM currently in use: 1) modification of the top of the AEM to provide hatch-type access; 2) construction of an Access and Transfer Unit (ATU) to allow transfer of rodents from the AEM while maintaining particulate containment; 3) construction of Rodent Holding Boxes, used to contain rodents during transfer from the AEM to the GPWS; 4) clean-up kits; and 5) spare gauntlets.

Subsystems —

AEM Hatches: The top of the AEM was modified to add hatches that mate with the Access and Transfer Unit (ATU) to permit the removal of rodents from the AEM into the ATU while maintaining particulate containment. Following removal from the AEM, the rodents were transferred to Rodent Holding Boxes inside the ATU.

Access and Transfer Unit (ATU): The ATU was primarily made of Lexan, with Tyvek gauntlets and a bladder-cloth sock between the ATU and the built-in General Purpose Transfer Unit (GPTU). Two hatches on the floor of the ATU sealed against the AEM hatches. The operator used gauntlets to reach inside the ATU and open the ATU and AEM hatches in unison to access the rodents. Once the rodents were removed, the operator replaced the ATU and AEM hatches, permitting the ATU to be detached from the AEM and allowing transport of the ATU to the GPWS. The built-in GPTU on the back of the ATU interfaced with the side access window of the GPWS for transfer of the Rodent Holding Boxes into the GPWS.

Rodent Holding Boxes: These containers, made of Lexan with an aluminum lid, were used to hold the rodents within the ATU during transfer operations to the GPWS. The lid contained ventilation holes and a fine mesh hydrophobic screen, and it was secured via latches. Two Rodent Holding Boxes could fit within the ATU.

Clean-Up Kit: The clean-up kit was used to clean the interior of the ATU and the Rodent Holding Boxes during operations. It consisted of dry and wet wipes, a set of q-tips within a plastic bag, and a spray bottle modified with an internal bag for double containment.

Spare Gauntlets: Spare gauntlets were flown to replace soiled gauntlets after completion of access operations in the AEM. Each pair of gauntlets, made of Tyvek, was stowed in a separate plastic bag.

Flight Experiments —

McNaughton, Bruce L. *Ensemble Neural Coding of Place and Direction in Zero-G*
Nowakowski, Richard S. *Reduced Gravity: Effects in the Developing Nervous System*
Walton, Kerry D. *Effects of Gravity on Postnatal Motor Development*

Anomalies — Anomalies encountered in the performance of the AEM/ATU during the mission affected the crew's interaction with the hardware, and therefore the operational timeline, but had no impact on the science.

Inflight, it was found that extensive crew time was required to mate the ATU to the AEM. More than one crew member was required to complete what was planned to be a one-person operation. The crew experienced substantial difficulties stabilizing the AEM once it was removed from the middeck locker. The tiedown straps intended for this purpose did not provide adequate restraint in the absence of gravity. On the ground, the weight of the AEM and static friction helped to

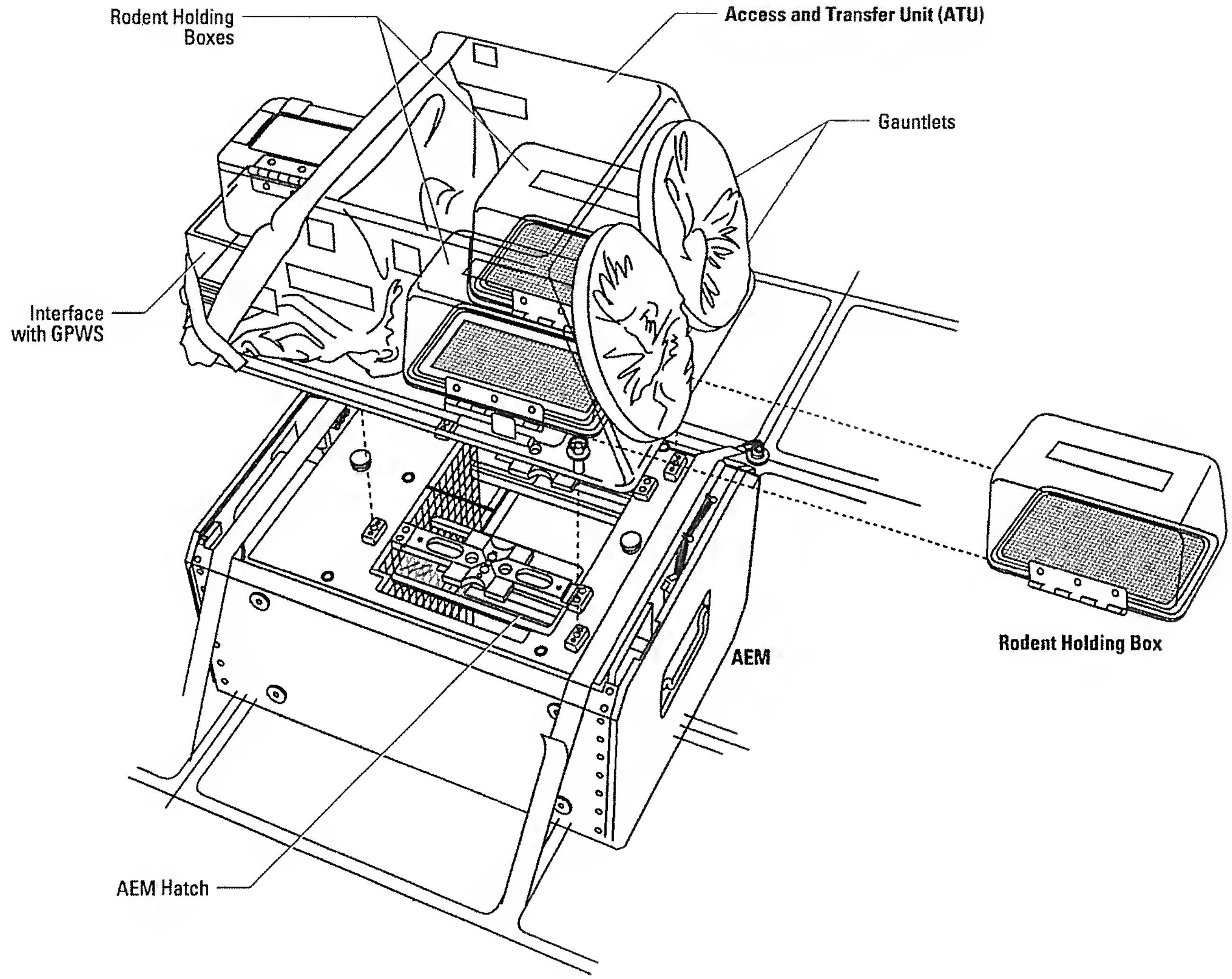

Figure 3.1 Animal Enclosure Module in Mating Configuration with the Access and Transfer Unit (Internal Contents Shown to Demonstrate Stowed Configuration)

immobilize the AEM during the tiedown operation. Inflight, one of the tiedown straps broke while the crew tried to secure and stabilize the AEM into a fixed position.

This design weakness was compounded by the method for attachment of the ATU to the AEM. Four quarter-turn fasteners inside the ATU were used to secure the ATU to the AEM. To accomplish this task, a crew member had to insert his arm inside the ATU gauntlet, compress a large sealing gasket, and engage each of the quarter-turn fasteners. This operation was successfully tested on the ground and performed by the crew prior to flight without any negative observations. Inflight, however, in the absence of gravity, the attachment procedure proved extremely difficult. First, the tiedown straps did not immobilize the AEM as they had on the ground. Second, in trying to reach inside the ATU, compress the gasket, and engage the quarter-turn fasteners, it was almost impossible not to apply a force with one's arm on the body of the ATU and cause the ATU to separate from the AEM. It required two to three crew members working in unison to complete the ATU/AEM attachment procedure. The AEM hatch locking latches were also troublesome during the flight. Because of their design, it was difficult to determine when they were positively locked in place. In addition, animal urine dried and crystallized on the AEM hatch seals. This made it difficult for the crew to remove the hatches and necessitated cleaning the hatch surface before re-sealing the AEM— activities that increased the time allotted to perform this operation.

Lessons Learned — The ATU and its interface to the AEM underwent very rapid prototyping, design, and production due to a late decision to demanifest the Advanced Animal Habitat (AAH) and replace it with an AEM with access capability (i.e., less than a year product cycle). The crew felt that the engineers involved in the construction of the ATU did the best they could within the limited time available for development. It is important to recognize that with a short development cycle and limited testing opportunities, the possibility of associated risk increases. Adding additional funding and personnel to a short development cycle does not necessarily eliminate risk. In this case, time and rigorous testing were also needed.

Most of the operational anomalies were a result of design/microgravity incompatibility. The Hardware Failure Review Board stated that more emphasis should have been placed on this factor during the hardware development, though it was understood that certain design attributes affected by the microgravity environment cannot always be predicted in a 1-G environment. Portions of the hardware design (access and particulate containment) were tested on the KC-135, but some critical design features (tiedown and ATU attachment to the AEM) were not ready in time for KC-135 testing. In addition to the design issues, the crew recommended that animal access operations not take place in the middeck in the future. The procedures were difficult to perform, and this was compounded by the limited space in the middeck and the other activities going on there simultaneously.

3.2.2 BOTEX Incubator

Reference Figure 3.2 for a drawing of the BOTEX Incubator

One BOTEX Incubator was flown on Neurolab in the Spacelab.

Description — BOTEX was a multipurpose incubator system. Originally designed for BOTany EXperiments, it could also hold small animals to enable research in zoology and related disciplines. It consisted of an incubator and a control unit. The incubator contained a 1-G reference centrifuge as well as upper and lower drawers to hold the experiment-specific

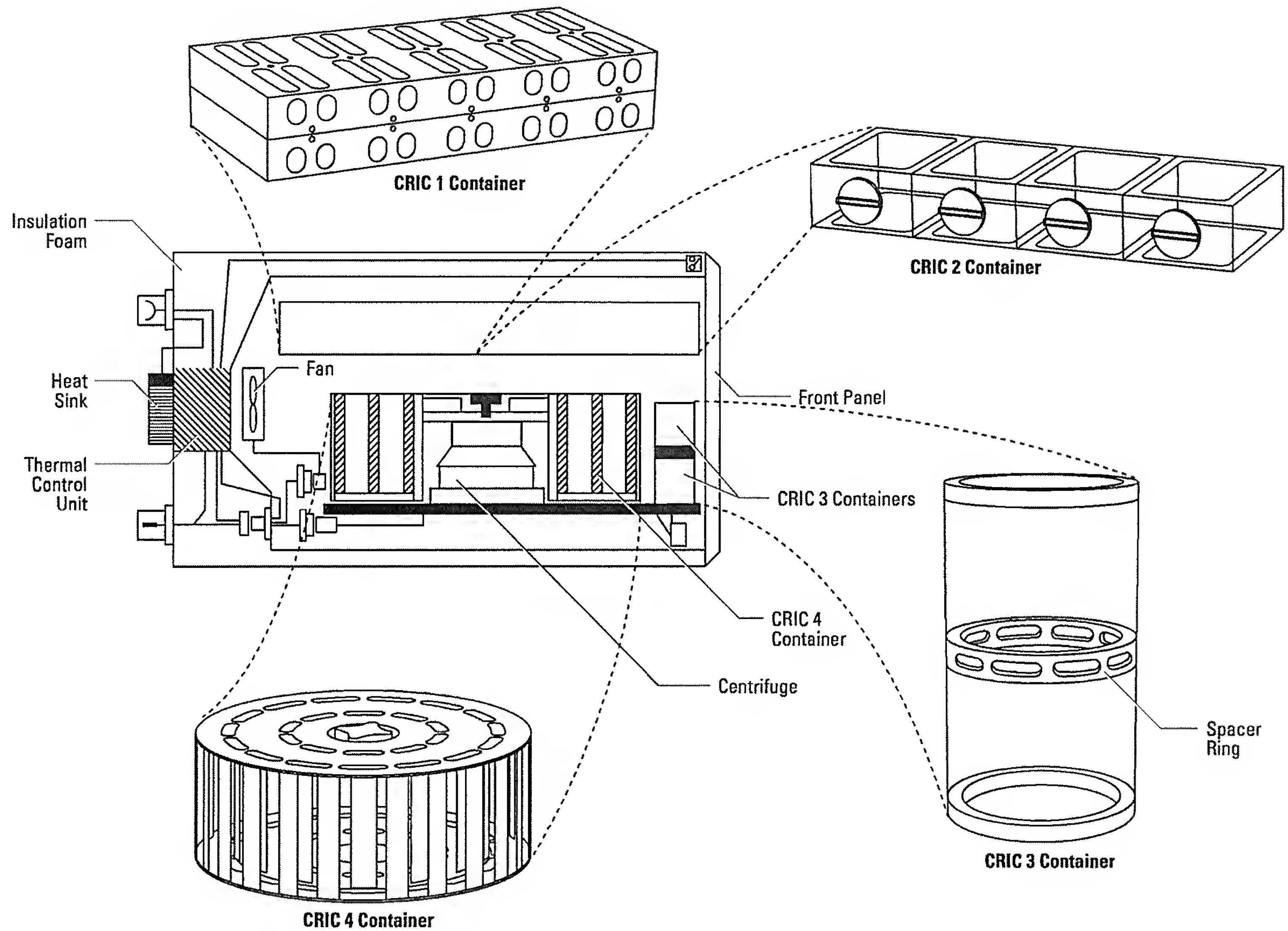

Figure 3.2 BOTEX Incubator

equipment. During launch and landing, this equipment was stowed in a large middeck locker tray. Different types of containers were available for holding plants, cells, or small animals.

For Neurolab, experiment-specific containers called CRIC (short for cricket) containers were used to hold the experiment organisms. CRIC containers were stowed in a middeck stowage tray for launch and landing.

Subsystems —

Gravitational Biology Control Unit: The control unit provided the power supply, control electronics, and Remote Acquisition Unit data interfaces for the incubator and centrifuge.

BOTEX Incubator Centrifuge: The centrifuge was a 1-G reference centrifuge located in the lower drawer of the BOTEX. The speed range was from 60 to 90 rpm with nominal operation at 90 rpm. A CRIC 4 container served as the centrifuge rotor.

Animal Housing Containers:

CRIC 1 Container: The CRIC 1 container (325 mm wide x 60 mm high x 160 mm diameter) served as a holding assembly for 40 minicages and was located in the upper drawer of the BOTEX during orbit.

CRIC 2 Container: The CRIC 2 container (330 mm wide x 60 mm high x 130 mm diameter) had four separate compartments, each with a wire mesh top and a circular door in the front. The container was located in the upper drawer of the BOTEX during orbit.

CRIC 3 Container: The cylindrical CRIC 3 containers (80 mm high x 100 mm diameter) were located in the lower drawer of the BOTEX in front of the centrifuge during orbit. The containers could be stacked, separated by a spacer ring to allow for air exchange.

CRIC 4 Container: The cylindrical CRIC 4 container (125 mm high x 330 mm diameter) could hold up to 60 minicages for centrifugation.

Flight Experiments — Horn, Eberhard R. *Development of an Insect Gravity Sensory System in Space*

Anomalies — The BOTEX unit did not experience any anomalies during the mission. Only one operational error occurred in the timeline of the related experiment, when the system deactivation and transfer of the CRIC containers to a middeck stowage locker occurred early on FD 17 instead of the prior evening, as planned.

3.2.3 Closed Equilibrated Biological Aquatic System (CEBAS)

Reference Figure 3.3 for a drawing of the Closed Equilibrated Biological Aquatic System.

One CEBAS was flown on Neurolab in the Space Shuttle middeck.

Description — The CEBAS Minimodule was a middeck-locker-sized fresh water habitat that allowed the controlled incubation of various aquatic species in a self-stabilizing, artificial ecosystem under ground and space flight conditions. Thus, scientific investigations could be enabled under the influence of the unique space environment for single organisms as well as for a whole ecosystem.

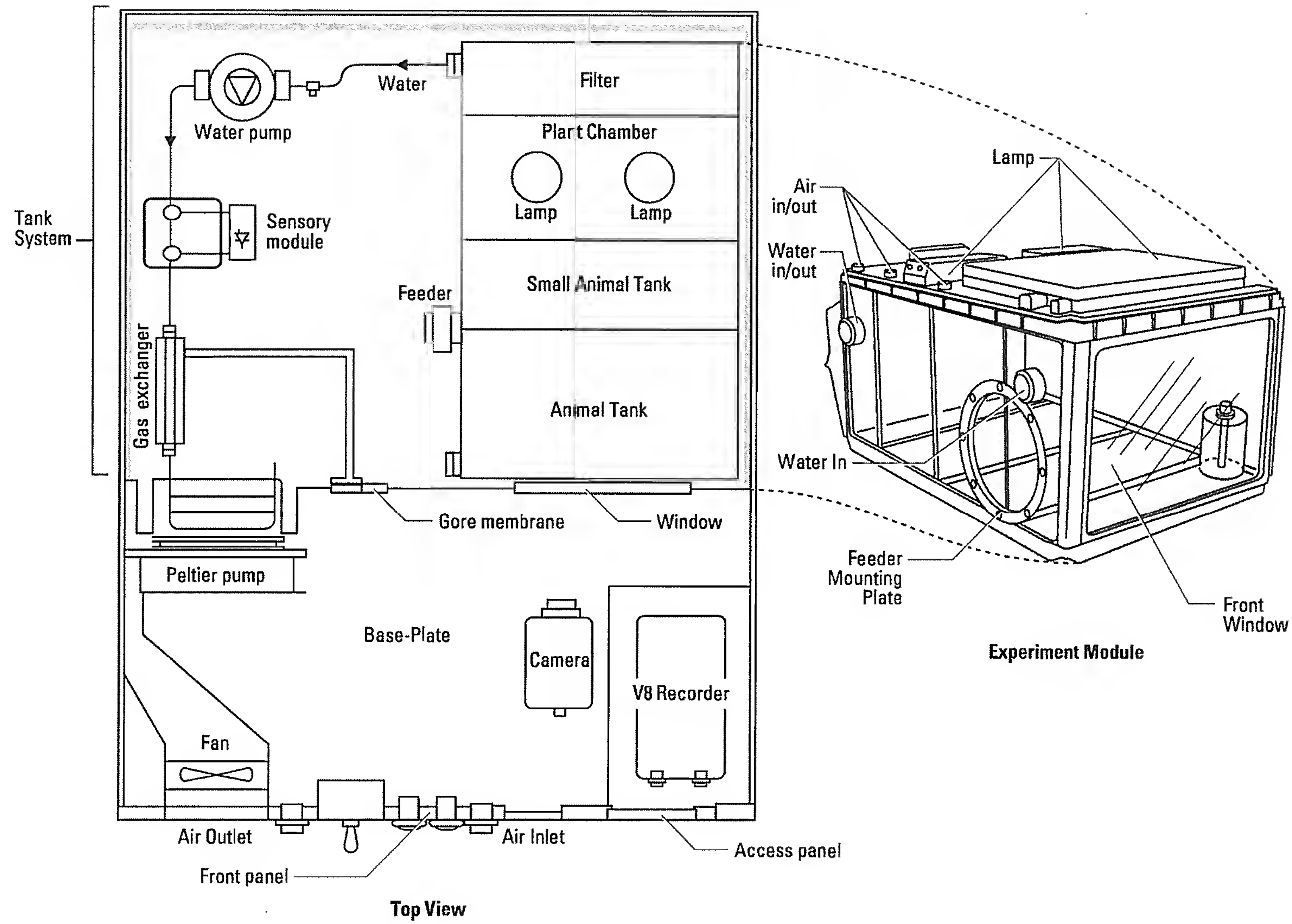

Figure 3.3 Closed Equilibrated Biological Aquatic System

The CEBAS Minimodule was developed at OHB-System, Bremen Germany, under contract to the German Aerospace Center, DLR.

The module design was based on prototypes of aquatic systems of different sizes developed and built at the C.E.B.A.S. Center of Excellence, University of Bochum, Germany. Utilizing these models, extensive ground testing proved the ecological stability of a biological system consisting of swordtail fish (*Xiphophorus helleri*), water snails (*Biomphalaria glabrata*), and micro-organisms as consumers and hornweed plants (*Ceratophyllum demersum*) and micro algae as producers. Thus, the water quality was maintained and regulated within the equilibrated biological aquatic system, where every organism served as an experiment object as well as an integral part of the life support and closed aquatic ecological system.

The system complied with the requirements (size, weight, power) for a Space Shuttle Middeck-Locker and was handled as a late access loaded item. A twin Minimodule allowed ground-reference experiments to be performed in parallel to the flight experiment. After flight and early retrieval, all biological samples were processed as necessary and distributed for postflight analysis.

The CEBAS Minimodule consists of two major subsystems.

Subsystems —

Experiment Module: The experiment module (housing unit) offered, in a modular way, up to four separate compartments for adult and larval stages of fish and snails, plants, and the microbiological filter system in a total water volume of 8.6 liters.

Support Module: The support module controlled water flow, thermal conditions, and illumination cycles as well as the monitoring and data storage of ambient temperature and water parameters such as temperature, pH, and oxygen concentration. A programmable video recording system allowed the scientist detailed observations of animal habitats for further analysis.

Flight Experiments — Wiederhold, Michael L. *Development of Vestibular Organs in Microgravity*

Anomalies — The CEBAS hardware had flown previously on STS-89, and no anomalies were reported during that mission. Filter clogging at the air inlet filters was observed postflight and higher-than-expected temperatures were recorded, but they remained within acceptable levels.

During Neurolab, on FD 13 through FD 16, the CEBAS cooling system failed to maintain the water temperature within the specified 25 ± 2 °C. The temperature reached its maximum of 29.5 °C on FD 16.

The Hardware Failure Review Board's findings were inconclusive, based on data provided, but suggested several possible causes for the high temperature. First, the CEBAS was placed next to the Crew Galley oven within the Shuttle middeck. According to crew comments post-mission, there could have been a bolus of hot air outside the oven in front of the CEBAS air inlet. The payload locker location was determined preflight and was based on available locker space, power access requirements, and competing locker assignments. No information was available from the previous flight to indicate any locker location constraints. Also, decreased oxygen concentration in the water supply later in the flight, around FD 9, automatically triggered the vegetation lamps to turn on. In turn, this caused the lamp cooling fans to turn on, which exhausted additional high temperature air in front of the CEBAS. Finally, during postflight inspection of the hardware, the

air inlet filter for the vegetation lamp cooling loop and controller heat sink was found to be almost completely blocked with lint and hair.

Lessons Learned — The Hardware Failure Review Board recommended that if the CEBAS hardware is to be used again, characterization tests should be performed to determine performance of the temperature control system under specified worst-case conditions. They also recommended that special attention be provided to the design and maintenance of inlet air filters for cooling systems, due to the known presence of lint, hair, and other particulates on manned space vehicles. The crew suggested that on future missions the CEBAS should be flown in the aft flight deck, which provides better air circulation and distance from a heat producer such as the galley.

3.3.4 E100 (McNaughton) Experiment Unique Equipment

Reference Figure 3.4 for a drawing of the E100 suite of hardware.

Description — The E100 suite of hardware was designed to monitor rodents to determine how their spatial orientation system performs and adapts under microgravity conditions, specifically, how 0-G affects firing properties of neurons in the hippocampus, the portion of the rodent brain in which location is sensed or determined. The E100 hardware allowed rodents to perform behavior tasks inflight while simultaneously recording the electrical activity from nerve cells. The components of the E100 experiment unique equipment were the Headmount Assembly, an electrophysiological recording head implant; the Escher Staircase and Magic Carpet, two behavioral testing devices; and the Data Acquisition System, which recorded neural activity from implanted electrodes, generated neural stimuli, recorded animal position and orientation, provided operator interfaces, and acquired video footage.

Subsystems —

Headmount Assembly: The Headmount Assembly consisted of three components: the Hyperdrive, the Headstage Amplifier, and the Headstage Cable Harness (also called the hyperdrive interface cable).

The Hyperdrive directly interfaced with the rodent brain. Its recording probe (tetrode) consisted of four separate microwires twisted together, each connected to a separate preamplifier channel and each referred to a common remote reference electrode. Each channel recorded the same extracellular spike signals, but the relative amplitudes on the four channels were a unique function of the spatial location of the neural generator. The system was capable of independently positioning 14 separate tetrode probes (12 experiment and 2 reference.) Each probe could be moved up or down to optimize the unit sampling as well as to sample from multiple depths in areas of the rodent brain. ARC engineers and technicians took an existing design of PI McNaughton's ground unit and developed a smaller, more robust design for flight.

The Headstage Amplifier increased the amplitude of the weak neuron firings to a voltage level that can be recorded and stored on digital media for later analysis.

The Headstage Cable Harness carried neurological signals from the headmount assembly to the interface box, and carries power from the interface box to the headmount assembly.

Behavioral Testing Devices:
Escher Staircase: This device consisted of three orthogonal planes. In these planes, a track permitted the test subject to walk in a continuous loop that has three 90-degree turns in its yaw axis interspersed with three 90-degree backward pitches. When the animal was returned to the starting point, it has completed only 270 degrees of yaw rotation. The staircase was designed to test whether a rodent's hippocampal locating system could maintain stable representations of the environment under 0 G. While on the staircase, a rodent was tracked with two cameras synchronized with the Data Acquisition System (DAS).

Magic Carpet: This device consisted of a two-dimensional cross-shaped track. As a rodent walked along the track, the track rotated 180 degrees in the pitch axis, followed by a 180-degree rotation in the roll axis. This placed the rodent facing 180 degrees opposite its original position without experiencing rotation in the yaw axis. Animals were tracked using two position sensors that were synchronized with the DAS.

Data Acquisition System (DAS): The data acquisition system recorded neural activity from the implanted electrodes, generates stimuli, records animal position, orientation, and acceleration, provides operator interfaces, and acquires video footage. As a means of risk mitigation, two DAS units were flown on Neurolab because of the complexity of the system and the limited environmental testing performed on the hardware. The DAS included the following components:

Interface Box: The Interface Box processed neurological signals and position data, transmitted formatted data to the Data Computer, and generated stimuli.

Data Computer: The Data Computer processed and stored experiment data, controlled the interface box, and communicated with the laptop user interface.

Camera Assemblies: Two cameras provided video coverage of the behavioral apparatus for position sensing and video recording. The cameras mounted to the General Purpose Work Station (GPWS).

Pointer Device: The pointer device provided an operator interface to the data system, located within the GPWS.

Laptop Computer: The laptop computer provided a second operator interface to the data system.

Flight Experiments — McNaughton, Bruce L. *Ensemble Neural Coding of Place and Direction in Zero-G*

Anomalies — The E100 Experiment Unique Equipment experienced no major anomalies during flight. One rat lost its headmount assembly, but the On Duty Veterinarian determined that euthanasia of the animal was not required. Data was successfully collected from the other implanted animals. One of the DAS units malfunctioned inflight, but because two DAS units were flown on the mission, the crew used the second to complete experiment procedures.

Lessons Learned — The crew found it impossible to work with four animals in the GPWS at once. Originally, the plan was to have all four instrumented animals in the GPWS. Animals not

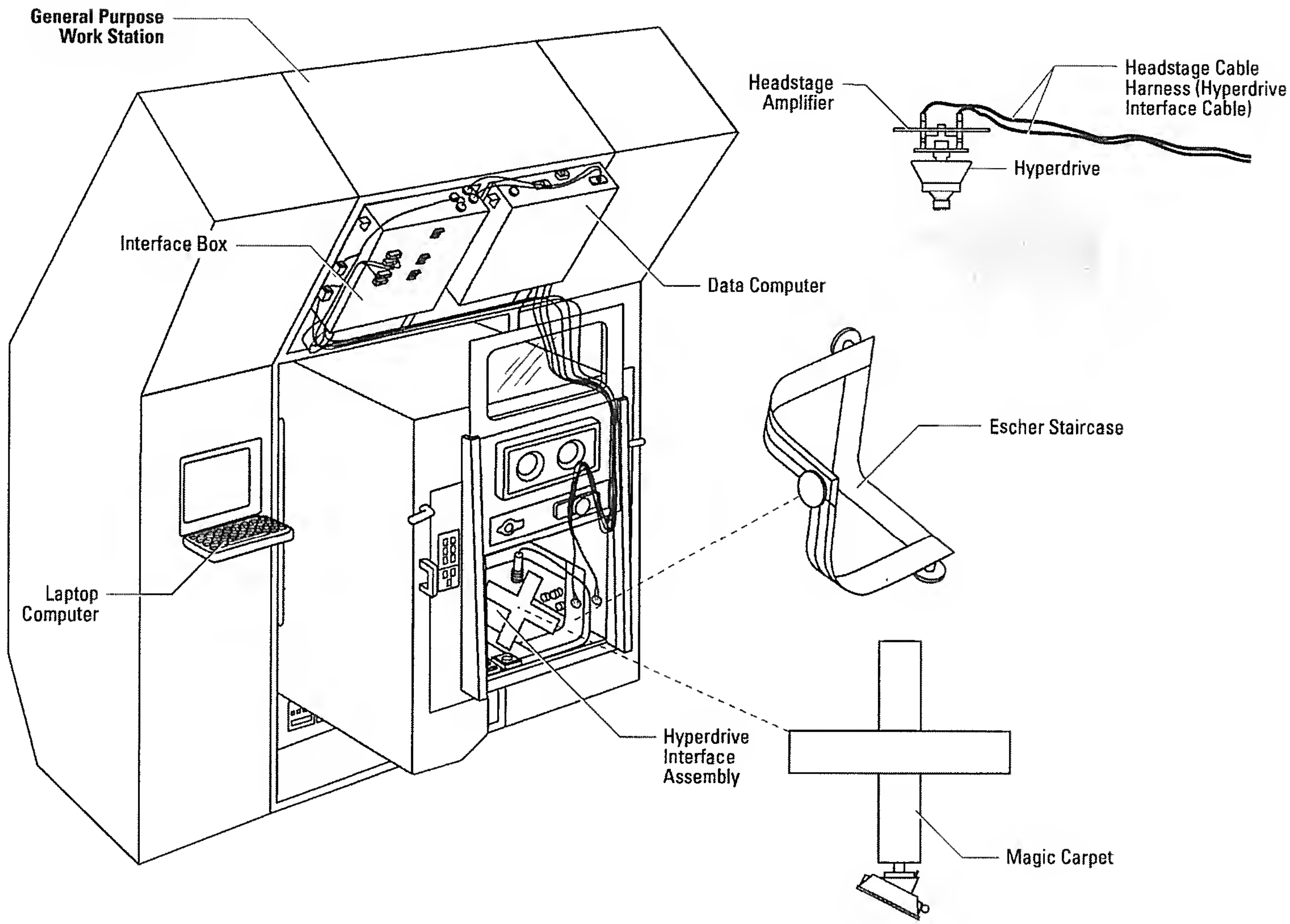

Figure 3.4 E100 Experiment Unique Equipment
(within and outside the General Purpose Work Station)

performing behavioral tests were to be kept in cloth pouches. The crew observed that there were too many objects floating in the work space and not enough airflow to keep animals within the holding pouches. In addition, a concern was raised that the animals may not be provided adequate airflow while in the pouches. The crew determined two animals to be the maximum number that should be in the GPWS at one time when this experiment was being performed.

When building components of a flight system at two widely separated locations (such as University of Arizona and ARC), it is paramount that frequent formal technical interface and hardware test meetings be established to drive the timely development of the flight design. It was only after such meetings were initiated by ARC that the flight system began taking shape. As it was, the flight hardware missed many critical milestones and the delays were impacting its readiness for flight.

3.3.5 E150 (Walton) Experiment Unique Equipment

Reference Figure 3.5 for a drawing of the E150 suite of hardware.

Description — The E150 Experiment Unique Equipment was designed to test and record rat neonate spatial-orientation behavior in microgravity. The hardware suite consisted of an Animal Walking Apparatus (AWA), a camera kit, a video cable kit, a video power kit, a video spares kit, and a dexterity video light.

Subsystems —

Animal Walking Apparatus (AWA): This device was designed to provide various motor challenges to rats inflight. A rectangular platform attached on one side to a backplate made up the core of the AWA. One side of the platform was covered in a wire mesh surface and one side was covered with foam. Experiment subjects could walk along either side in microgravity. The AWA also contained four round metal dowels of varying diameters, surrounding the platform and also attached to the backplate. The animals were either placed on the platform or a dowel. Younger rats could use the platform and the smaller dowels, and older rats had the motor control to use the platform and all of the dowels. Animals were marked in 16 places along the body and videotaped in two dimensions for later positional analysis. During flight, the AWA was deployed in the GPWS to conduct the experiment sessions.

Camera Kit: The camera kit consisted of two Sekai RSC-90 cameras (modified to JSC specifications) pre-attached to brackets. The crew used the cameras to videotape the animals using the AWA.

Video Cable Kit: Video cables provided power to cameras and a signal to the TEAC video recorders

Video Power Kit: The video power kit included a power supply, a cloth backdrop to increase contrast in the GPWS (to increase quality of the video), a strobe (used to give the light pulse to synchronize the cameras), and a Research Animal Holding Facility cage cover.

Video Spares Kit: The video spares kit included a spare strobe, a spare camera, and spare video cables.

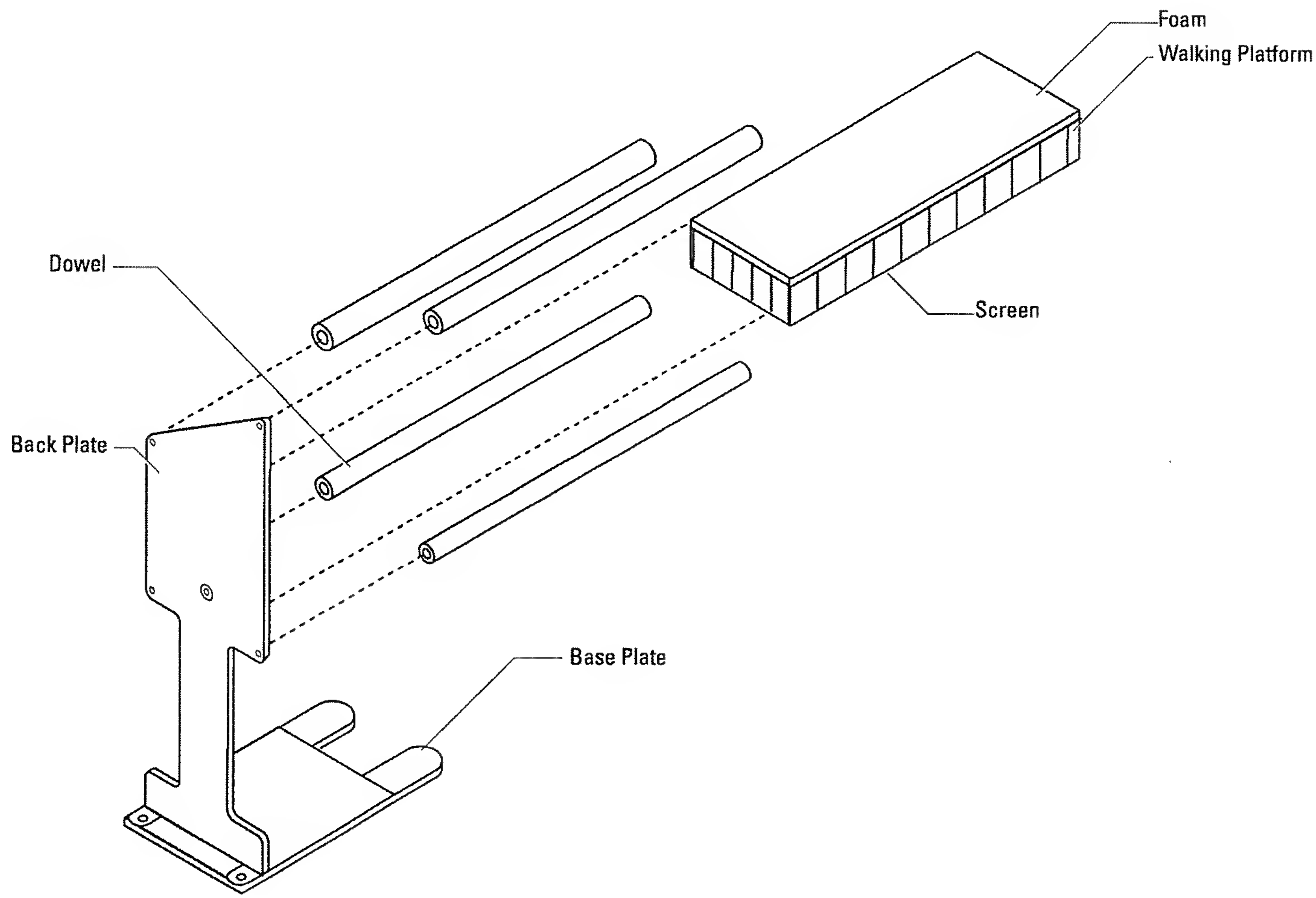

Figure 3.5 E150 Animal Walking Apparatus

Dexterity Video Light: The dexterity video light was a fluorescent light placed under the AWA to provide light for activities that took place under the AWA platform, such as when an animal walked around the end of the platform and on to the lower surface or was placed on the lower dowels.

Flight Experiments — Walton, Kerry D. *Effects of Gravity on Postnatal Motor Development*

Anomalies — The E150 Experiment Unique Equipment operated nominally during flight.

Lessons Learned — Construction of the E150 EUE required close coordination between engineering, science, and crew training. The experiment was not fully developed by the PI prior to hardware development; therefore, Engineering and Science participated in much of the requirements definition. During development of the Animal Walking Apparatus and related hardware, engineering did not have direct access to the PI and crew comments related to the prototype hardware. As a result, the flight hardware underwent several last-minute changes to incorporate important PI and crew recommendations. In the future, engineering should be directly involved in all prototype hardware evaluation sessions and crew training exercises to ensure that all critical performance features are captured in the flight hardware design.

3.2.6 General Purpose Work Station

Reference Figure 3.6 for a drawing of the General Purpose Work Station.

Description — The General Purpose Work Station (GPWS) was a multipurpose support facility for conducting general laboratory operations within the Spacelab. The GPWS supported biological experiments, biosampling, and microbiological experiments, and it served as a closed environment for containment while routine equipment repair or other inflight operations were performed. The GPWS provided the essential working space and accommodates the laboratory equipment and instruments required for many life sciences investigations. Housed in a Spacelab double rack, the GPWS was self-contained, apart from power, data, and cooling interfaces.

The GPWS has been described in detail in several other NASA technical publications. For a complete description of the facility, please refer to the Spacelab Life Sciences-1 Final Report, NASA TM-4706, or the NASA Life Sciences Data Archive (http://lsda.jsc.nasa.gov).

For Neurolab, dissections, perfusions, and behavioral activities were conducted inside the GPWS. The GPWS was treated as previously flown hardware, with only minor modifications made before flight. Most changes involved the integration of experiment-specific hardware for the E100 and E150 experiments, including two video cameras mounted inside the GPWS to record activities for these experiments and an interface box mounted on the outside of the GPWS to provide power to the video cameras.

Experiments —
Six experiments directly used the GPWS (primary experiments, listed below), while the remaining experiments (secondary experiments, listed below) benefited by receiving tissues from the dissections for PIs Riley, Raymond, and Fuller.

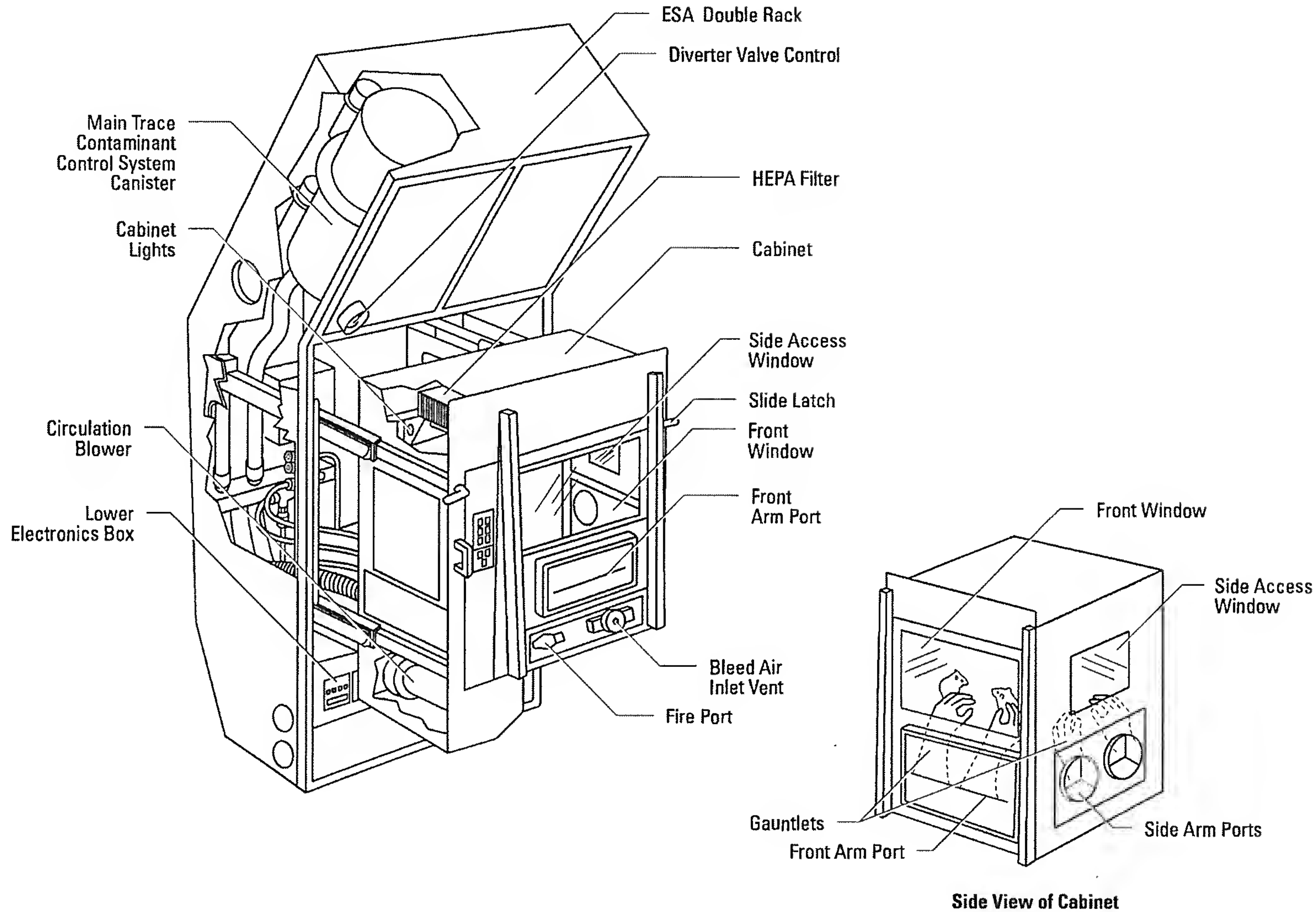

Figure 3.6 General Purpose Work Station

Primary Experiments:
Fuller, Charles A. *CNS Control of Rhythms and Homeostasis during Space Flight*
McNaughton, Bruce L. *Ensemble Neural Coding of Place and Direction in Zero-G*
Nowakowski, Richard S. *Reduced Gravity: Effects in the Developing Nervous System*
Raymond, Jacqueline. *Microgravity and Development of Vestibular Circuits*
Riley, Danny A. *Effects of Microgravity on Neuromuscular Development*
Walton, Kerry D. *Effects of Gravity on Postnatal Motor Development*

Secondary Experiments:
Holstein, Gay R. *Anatomical Studies of Central Vestibular Adaptation*
Kosik, Kenneth S. *Neuronal Development under Conditions of Space Flight*
Pompeiano, Ottavio. *Effects of Microgravity on Gene Expression in the Brain*
Ross, Muriel D. *Multidisciplinary Studies of Neural Plasticity in Space*
Shimizu, Tsuyoshi. *Development of the Aortic Baroreflex under Conditions of Microgravity*

Anomalies — The GPWS experienced one minor anomaly during flight. The door on the work station failed once, requiring the hinges to be tightened. Complaints about the GPWS related more to ergonomic issues rather than to hardware performance.

Lessons Learned — Postflight, crew members reported that they consistently experienced lower back pain from working in the GPWS. Some braced their head against the work station window to hold their torso rigid while performing operations such as dissections. In debriefs, they mentioned that an ergonomic chair to stabilize the lower body would be an important addition. The chair would also help supply additional stabilization while performing dissections. The crew also recommended the need for a voice-activated data entry system, as well as an allocation of a backup crew member to help with GPWS operations. Based on information obtained from previous flights with the GPWS, it is critical that an operator's height be factored into how the system will be used and the planned duration of an operation. Previously flown crew members who were shorter in stature did not report similar concerns.

3.2.7 Microinjection Kit

Reference Figure 3.7 for a drawing of the Microinjection Kit.

Description — The Microinjection Kit was developed for inflight injection of a biomarker into rat muscle. A microinjection syringe contained in the kit dispenses accurate, repeatable volumes of fluid under standard conditions. Each kit contained five 25-μl microsyringes. Each syringe dispensed 0.5 μl of solution for each press of the dispense button.

In the kit, a surface-mounted sheath secured to the tray protected the 32-gauge syringe needles. A syringe shroud protected the thin plunger rod. A soft silicon septa plug was attached to the syringe needle for needle protection. Heat shrink wrap protected the glass syringe barrel from breakage. The microsyringes were stowed with the plunger assembly extended and restrained by a surface-mounted mechanical stop, which prevented accidental discharges. A double-compartment polyethylene bag secured by a double clamp assembly contained the kit.

Experiments —
Riley, Danny A. *Effects of Microgravity on Neuromuscular Development*

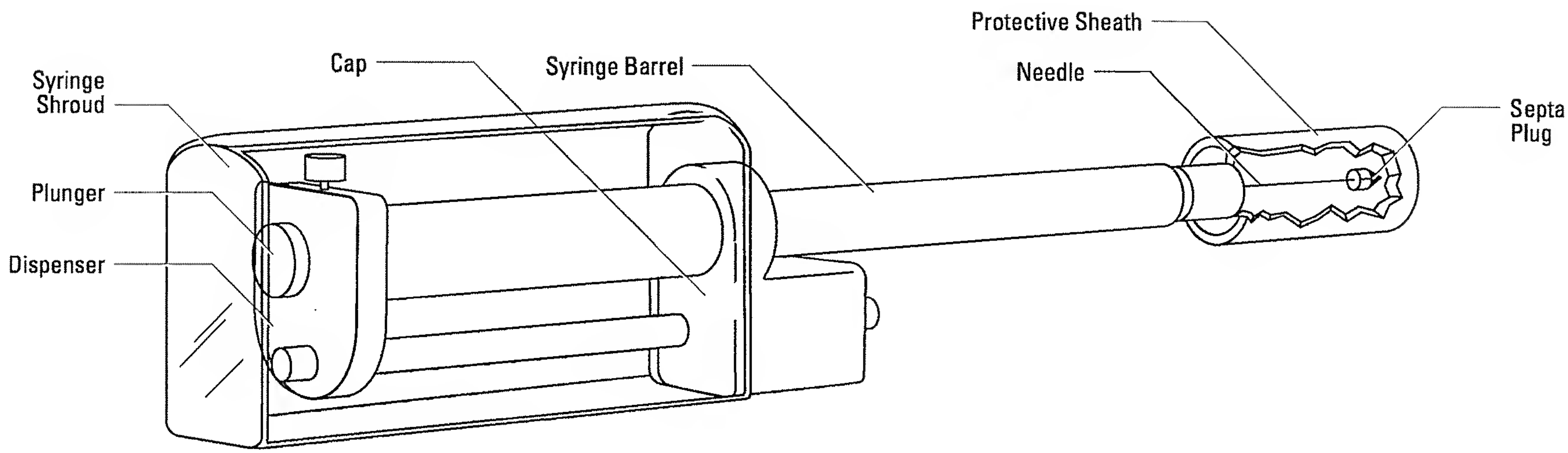

Figure 3.7 Microinjection Kit

Anomalies — The Microinjection Kit operated nominally during flight. The microsyringes would not fit back onto the kit backplate after use, but this resulted in no science loss.

Lessons Learned — Engineering should consider not only how an item is stowed, but also its condition after use and return to stowage.

3.2.8 Neurolab Biotelemetry System (NBS)

Reference Figure 3.8 for a drawing of the Neurolab Biotelemetry System.

Description — The Neurolab Biotelemetry System (NBS) processed sensor data from implanted animals. It consisted of sensors and transmitters implanted within the research animals; antennas; amplifier combiners; dual receivers; demodulators; and control systems that gathered, processed, displayed, and stored data for later evaluation.

Subsystems —

Cage System: Standard Research Animal Holding Facility (RAHF) cages housed the implanted animals. Twelve rodents, housed in six cages, were implanted with sensors and transmitters, which transmit deep body temperature and electrocardiogram (ECG) data. Signal strength from the transmitter was used to record animal activity counts. Each battery-powered transmitter had a life of 10 months. Each cage possessed two antennas mounted on the side of the cage (one per animal compartment) that received the signal from the implants. Antenna amplifier combiners, associated with each cage and mounted on the rear of the cage, amplified and combined the two antenna signals and sent the resulting signals to receivers located in the Neurolab Biotelemetry Chassis (NBC).

Neurolab Biotelemetry Chassis (NBC): The Neurolab Biotelemetry Chassis, the main control unit for the biotelemetry system, provided the required electrical and mechanical interfaces to Spacelab. It came equipped with side-mounted chassis slides to allow removal for servicing. The NBC occupied an 8-panel unit space in the upper Spacelab rack assembly.

Experiments — Fuller, Charles A. *CNS Control of Rhythms and Homeostasis during Space Flight*

Anomalies — The NBS experienced no anomalies during flight. Data were collected as required for the Fuller experiment.

Lessons Learned — Major system testing, beyond the normal testing required by the payload and PI (baseline testing, biocompatibility, EVT, etc.) was required for this system to define and eliminate inherent system noise in the flight and ground systems. Through extensive testing and noise-suppression rework of the hardware, the required design specifications for the flight and ground support hardware were finally met. The additional testing required was superimposed on the hardware integration schedule, which made the flight hardware integration process more hectic and interactions with KSC more contentious than normal. In this case, the engineering schedules were very aggressive and did not have enough flexibility to accommodate all that was planned or opportunities for rework. Negotiation should have been initiated earlier to develop a simplified and more agreeable integration schedule with KSC.

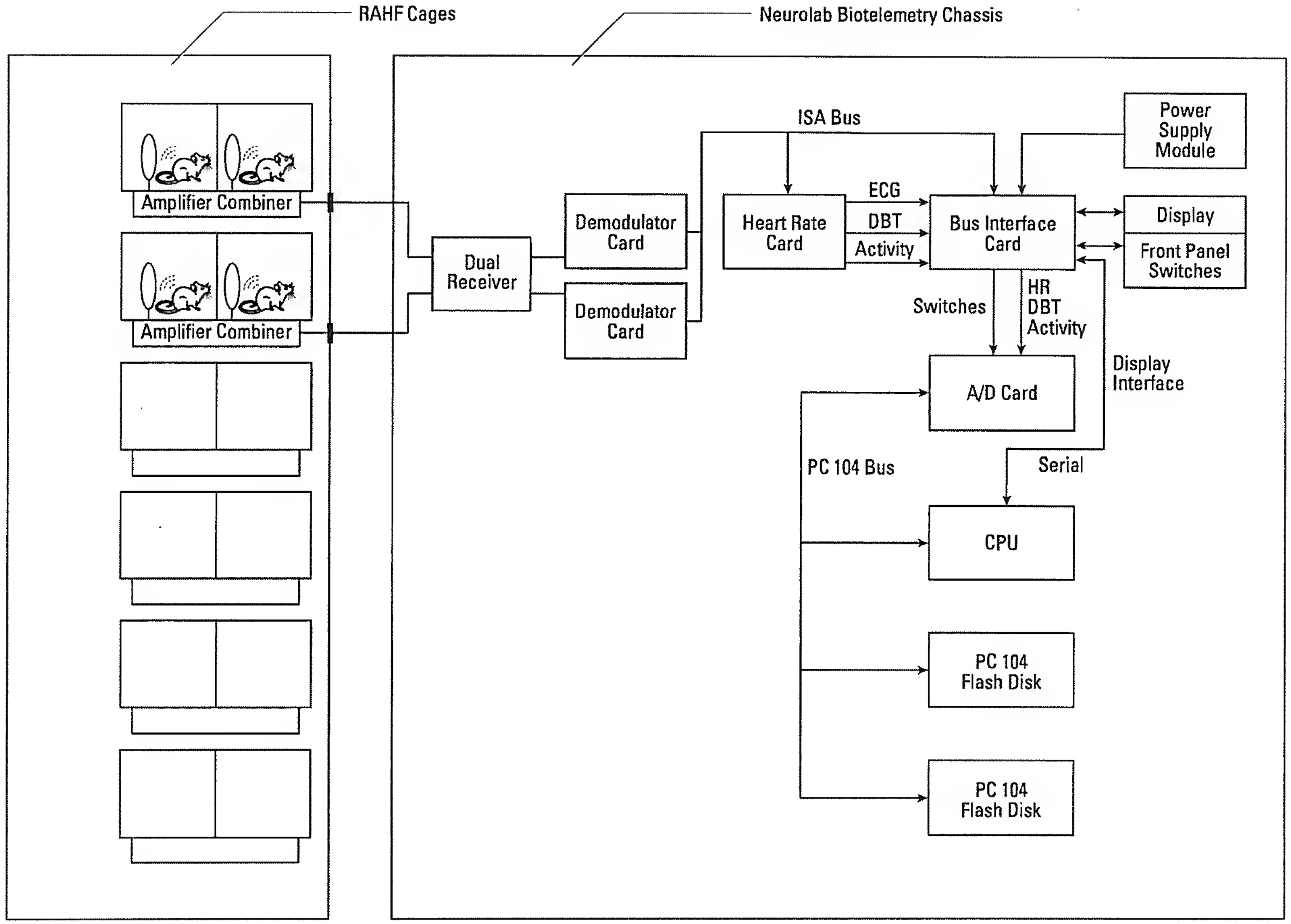

Figure 3.8 Neurolab Biotelemetry System

3.2.9 Perfusion Warmer Bag Assembly

Reference Figure 3.9 for a drawing of the Perfusion Warmer Bag Assembly.

Description — The Perfusion Warmer Bag assembly was originally built at Johnson Space Center to hold and heat two saline solution bags over several hours. Ames Research Center modified the original design to heat 16 syringes of phosphate buffer solution to 37 °C± 2 °C within two hours (for use in the inflight perfusions). Two aluminum heat frames (also called a heat sink) were constructed to conduct heat along the sides of the bag. Syringes were packed in groups of two within the bag, placed plunger-to-needle within a pair. Copper foil was wrapped around each syringe pair to aid with head transfer. The bag received power from the Experiment Power Switching Panel located on the underside of the GPWS.

Extensive ground testing of the design was conducted to verify that the Perfusion Warmer Bag Assembly would perform to specifications inflight.

Experiments —
Baldwin, Kenneth M. *Neural Thyroid Interaction on Skeletal Isomyosin Expression in Zero-G*
Kosik, Kenneth S. *Neural Development under Conditions of Space Flight*
Raymond, Jacqueline. *Microgravity and Development of Vestibular Circuits*
Riley, Danny A. *The Effects of Microgravity on Neuromuscular Development*
Shimizu, Tsuyoshi. *Development of the Aortic Baroreflex under Conditions of Microgravity*
Walton, Kerry D. *Effects of Gravity on Postnatal Motor Development*

Anomalies — The Perfusion Warmer Bag Assembly operated nominally during flight.

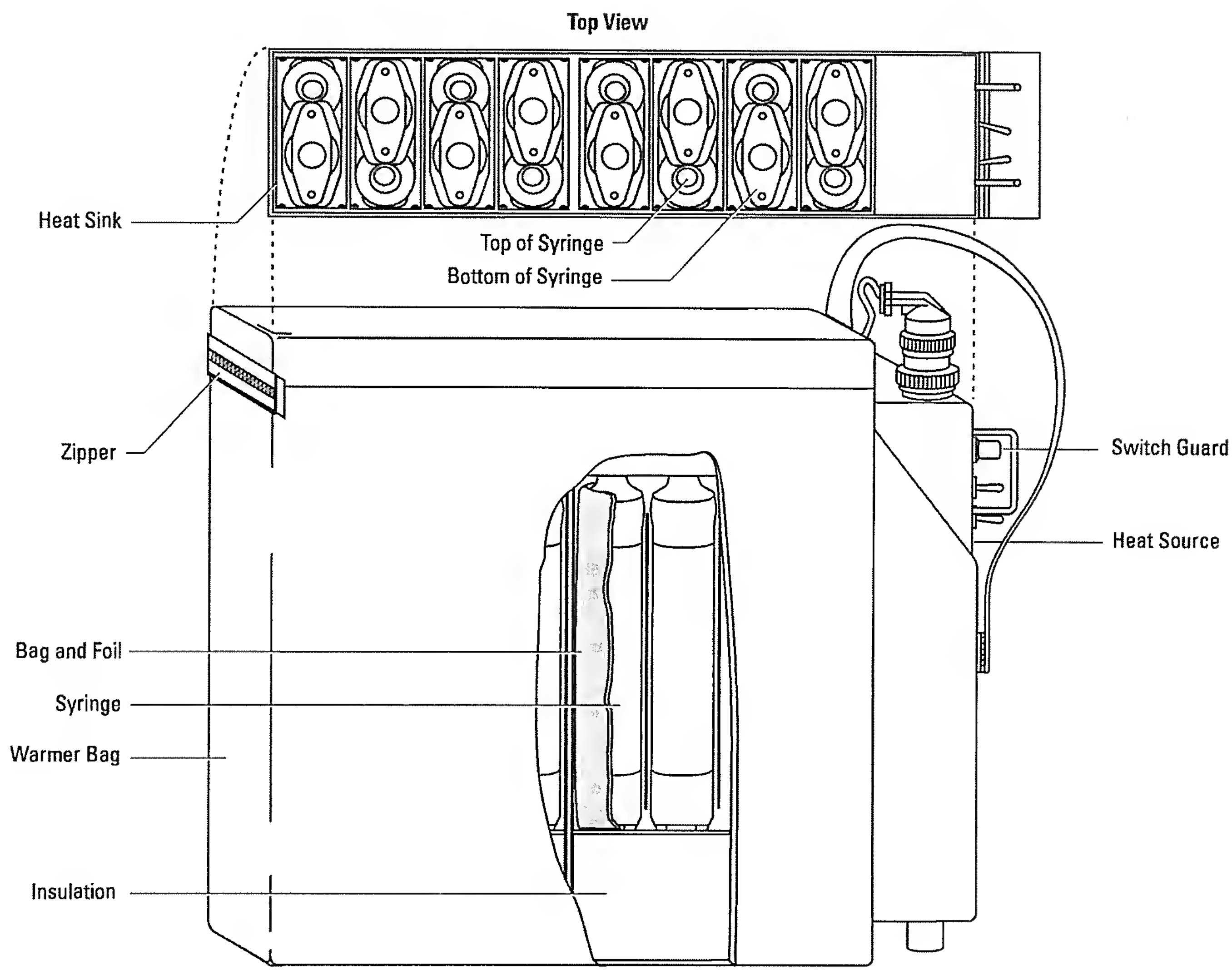

Figure 3.9 Perfusion Warmer Bag Assembly

3.2.10 Research Animal Holding Facility (RAHF)

Reference Figure 3.10 for a drawing of the Research Animal Holding Facility.

Two RAHFs were flown on Neurolab in the Spacelab.

Description — The Research Animal Holding Facility (RAHF) was a general use animal habitat built to fit within a Spacelab rack. Cage modules inserted into the RAHF to provide housing for research organisms. Within each module were specially designed cages for the type of animal being flown. These cages provided food, water, and waste management functions during the flight. In order for the RAHF system to provide a viable habitat, heating, cooling, lighting, air ventilation, and monitoring systems were provided.

Each RAHF contained one cage module that held 12 cages. Each module was divided into four quadrants; each quadrant contained three cages and had independent lighting control. Each cage contained food and water delivery systems and waste tray hardware designed to meet animal maintenance requirements, contain waste, and prevent Spacelab contamination.

The RAHF has been described in detail in several other NASA Technical Memoranda. For a complete description of the facility, please refer to the Spacelab Life Sciences-1 Final Report, NASA TM-4706, or the NASA Life Sciences Data Archive (http://lsda.jsc.nasa.gov).

For Neurolab, several major upgrades and changes were made to the RAHF design. The most comprehensive change was transitioning from the outdated controls to a fully embedded computer control system called the Monitoring and Process Control System (MPCS). Concurrent with switching to the MPCS, selected cables in the RAHF were replaced with new cabling to handle the inputs and outputs for the new system.

Within the Environmental Control System, the Thermoelectric Units (TEUs) were overhauled. The old TEUs had corroded due to long-term moisture and condensation exposure, and as a result, had decreased in efficiency. A new water separator system was installed (with an improved Condensate Collection Reservoir) with increased circulation and less noise output. No changes were made to the Single Pass Auxiliary Fan (SPAF).

For the water system, a quick disconnect port was added to the front of the cage in the feeder alcove so crew could verify that water is available to the lixits. The drinking water manifolds were overhauled to increase the accuracy of the water counts. In addition to the work on the drinking water manifolds, the RAHFs required modifications to correct problems with the blind mate quick disconnects, which are part of the cage assemblies and cage module. This difficulty, the result of repeated cage insertions into the modules, affected the water flow continuity to the cages and therefore required modification to assure a reliable water flow.

For Neurolab, three different rodent cage configurations were created: 1) standard adult cage; 2) neonate/nursing cage; and 3) biotelemetry cage. The neonate cages were modified from the standard adult rodent cage by the removal of the partition between the two standard rodent compartments and the addition of an insert that created potential huddling space for the resident dam and her neonates. The biotelemetry cages were wired to receive telemetry signals from rodent implants.

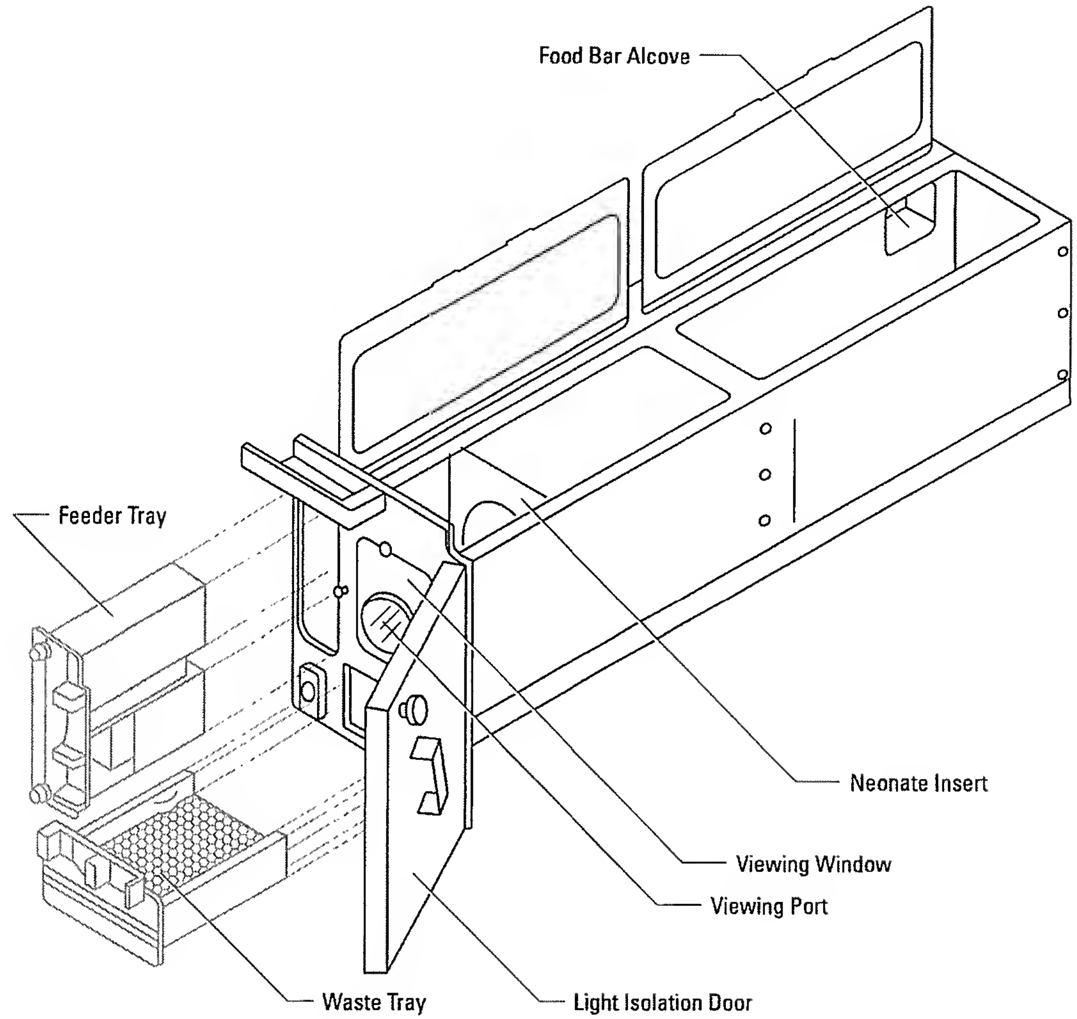

Figure 3.10 Research Animal Holding Facility Cage
(Neonate/Nursing Cage Configuration)

Two RAHFs were flown on Neurolab. One, designated RAHF 7, housed 24 adult rats (one per cage compartment) in either standard adult cages or biotelemetry cages. The other, designated RAHF 3, housed 12 dams and their litters in neonate/nursing cages. The RAHF 7 rack was fitted with a new Biotelemetry System that interfaced with the antenna systems of the biotelemetry cages.

Experiments —
Baldwin, Kenneth M. *Neural Thyroid Interaction on Skeletal Isomyosin Expression in Zero-G*
Fuller, Charles A. *CNS Control of Rhythms and Homeostasis during Space Flight*
Holstein, Gay R. *Anatomical Studies of Central Vestibular Adaptation*
Kosik, Kenneth S. *Neural Development under Conditions of Space Flight*
Pompeiano, Ottavio. *Effects of Microgravity on Gene Expression in the Brain*
Raymond, Jacqueline. *Microgravity and Development of Vestibular Circuits*
Riley, Danny A. *The Effects of Microgravity on Neuromuscular Development*
Ross, Muriel D. *Multidisciplinary Studies of Neural Plasticity*
Shimizu, Tsuyoshi. *Development of the Aortic Baroreflex under Conditions of Microgravity*
Walton, Kerry D. *Effects of Gravity on Postnatal Motor Development*

Anomalies — Two anomalies occurred in the functioning of the RAHF during Neurolab. On FD 8, the bleed air fans in RAHF 7 stopped operating during normal operations. Crew connected the air ducting from RAHF 7 to RAHF 3, and the RAHF 3 bleed air fans were utilized to force the air exchange for the duration of the mission. On FD 13, two of the four circulation fans in RAHF 3 stopped operating, reducing the airflow from 80 to approximately 60 cubic feet per minute.

A more significant issue than this off-nominal hardware performance was biocompatibility. Although numerous ground tests had demonstrated the biocompatibility of the RAHF cage with neonates (reference pp. 85-86 in the Operations section), the PN8 neonates did not fare well in the RAHF environment in microgravity. The crew observed the animals lodging themselves in the feeder cassette through the alcoves and one was wearing a lixit collar that became detached. The cage geometry made it difficult for the dam and neonates to engage in their normal huddling behavior. In addition, the force of the SPAF (when operating during RAHF cage access procedures) pulled neonate limbs and tails down through the cage mesh. The weakened animals had difficulty fighting the airflow. Overall, there was a higher mortality than expected among the neonates housed in the RAHF. Adult Neuronal Plasticity animals did not experience any notable difficulties in the RAHF.

Lessons Learned — The Hardware Failure Review Board (HFRB) found the cause of the bleed air fan failures to be inconclusive, but the power supply circuit for the fans was identified as being the most likely cause of failure. Engineering was unable to confirm this suspicion during extensive postflight testing of RAHF subsystems.

Inspection of the circulation fans revealed the cause of failure as mechanical interference; a piece of foreign object debris, in this case a Velcro twist tie used in one of the many containment bags, was caught in the fans. The RAHF did not have an inlet protective screen upstream of the first set of Circulation Fans. The path of entry was more than likely the front of the RAHF when a cage was removed, as there are no pathways through the front of the RAHF. The HFRB recommended that a standard design practice should be applied to include some minimum screen/filtration mechanism on the inlet path of all fans utilized in space flight applications. It is also prudent that if the interior of the hardware is to be accessed nominally or off-nominally, all pathways to fans should have a screen in line.

3.2.11 Vestibular Function Experiment Unit (VFEU)

Reference Figure 3.11 for a drawing of the Vestibular Function Experiment Unit.

Two VFEUs flew on Neurolab in the Spacelab.

Description — The VFEU was a rack-mounted piece of hardware built to provide life-support capability for the Oyster toadfish, *Opsanus tau*, in the Shuttle Spacelab. The VFEU contained two major subsystems: the Fish Package Control Unit (FPCU) and two Fish Packages (FP). The Neural Data Acquisition System (NDAS), consisting of the Telemetry System, the Data Recorder (DR) and the Data Interface Unit (DIU), was used for fish neural data acquisition in addition to the VFEU. Each Fish Package included a fish container that houses one fish (implanted with multichannel electrodes or microwire electrode) in artificial seawater. Two fish total could be housed in each VFEU.

Subsystems —

Fish Package Control Unit (FPCU): The FPCU was the main structural housing unit and the controller for the Fish Packages. Each FPCU held two Fish Packages.

Fish Package (FP): The FP held one toadfish within a fish container, which had a front window, water pump, air pump, water accumulator, artificial lung, and water purification system. The Telemetry Data Processing Unit (TDPU) and receiver of the NDAS were assembled on the FP.

Neural Data Acquisition System (NDAS): The NDAS was composed of the Data Interface Unit (DIU), the Data Recorder (DR), the Telemetry Data Processing Unit (TDPU), transmitters (Tx), receivers (Rx), a tank coil, and a wire harness. The purpose of the NDAS was to monitor the nerve impulse and the acceleration signal from toadfish within the Fish Packages.

Data Interface Unit (DIU): The DIU received the measurement data from the TDPU on each FP. The data were then sent to the Data Recorder.

Data Recorder (DR): The DR recorded fish neural and acceleration data, water temperature and pressure, acceleration of the FP, and the time code.

Water Sample and Refill Kit: The Water Sample Kit contained syringes with bags and a needle guide for FP water sampling. The Water Refill Kit contained syringes filled with seawater or freshwater for FP water supplement.

Overslide Protection Kit: To prevent the FP from sliding out of the FPCU during acceleration operations performed by the crew, an Overslide Protection Wire was attached between the FP and FPCU, and a stopper was attached to the VFEU Front Panel just before the operation is performed. This wire protected the FP from sliding over 25 cm and the stopper prevented the FP from quick disconnect-reconnection damage during the operation.

Experiments — Highstein, Stephen M. *Chronic Recording of Otolith Nerves in Microgravity*

Anomalies — The VFEU experienced three anomalies during the mission. In two of the FPs, units 2 and 3, the individual air pumps failed, resulting in the loss of ability to provide air/oxygen to their respective water tanks. The air pump in FP3 failed on FD 2 and the air pump on FP2 failed on FD 7. Fortunately, an In-Flight Maintenance Procedure had been prepared beforehand in

case of such a situation. The procedure was performed successfully inflight and life support remained adequate for the duration of the mission.

Upon landing, it was found that the Toadfish in FPs 1 and 4 had died inflight. An investigation into possible causes was conducted.

On FD 13 the VFEU Data Recorder went into an error state resulting in approximately 2.5 hours of lost data. Crew members shut off and re-initiated the power to the data recording system, which cleared the error.

Lessons Learned — The air pumps used in the VFEU are considered Limited Operating Life Items (LOLI). Both the pumps that failed had undergone refurbishment by NASDA in the months leading up to the mission. The two that did not fail came from the original equipment manufacturer. Although data provided by NASDA was inconclusive on the cause of the failure, the Hardware Failure Review Board came to the conclusion that it was most likely caused by the use of incorrect refurbishment materials on either the pump housing or fan blade materials (resulting in increased rotational friction). A consensus was reached that in the future, vendors must provide verification that correct materials are used during refurbishment, and a correctly refurbished air pump must demonstrate a minimum operational life longer than the planned flight duration.

Water sample analysis was performed for FPs 1 and 4, but no conclusive evidence could be found on what caused the inflight mortalities.

The HFRB does not recommend crew intervention to resolve a situation like the failure of the VFEU Data Recorder in the future. They suggested building in a start/stop signal that could automatically solve data stream sequence problems without crew intervention.

3.2.12 Kits and Miscellaneous Stowage

Description — The Neurolab mission required almost 500 total pieces of stowed hardware (reference Attachment 2). The design, fabrication, and verification of more than 40 unique stowage kits for the ARC portion of the Neurolab Mission proved to be a huge task for the payload's Engineering, Operations, and Science teams. In addition to the stowage challenges this volume presented, the science plans included numerous additional rack-mounted hardware elements (AAEU, VFEU, STATEX, BOTEX), which occupied potential stowage space.

Anomalies — The stowage items (other than those associated with rack mounted hardware) operated nominally during flight.

Lessons Learned — In a postflight report, the Engineering team in charge of stowage stated that their most important lesson learned was that Engineering must be involved with requirements and procedure definition at the outset, working with the Science team and the PIs, during procedure development and crew training sessions. The Neurolab stowage design effort began two years prior to launch. Prototype hardware was needed almost immediately, yet, the engineers had no hard technical requirements to work from. The requirements, procedures, and designs continued to change as critical mission milestones approached, resulting in repeated rework of hardware, revision of operational procedures, and impact on crew training.

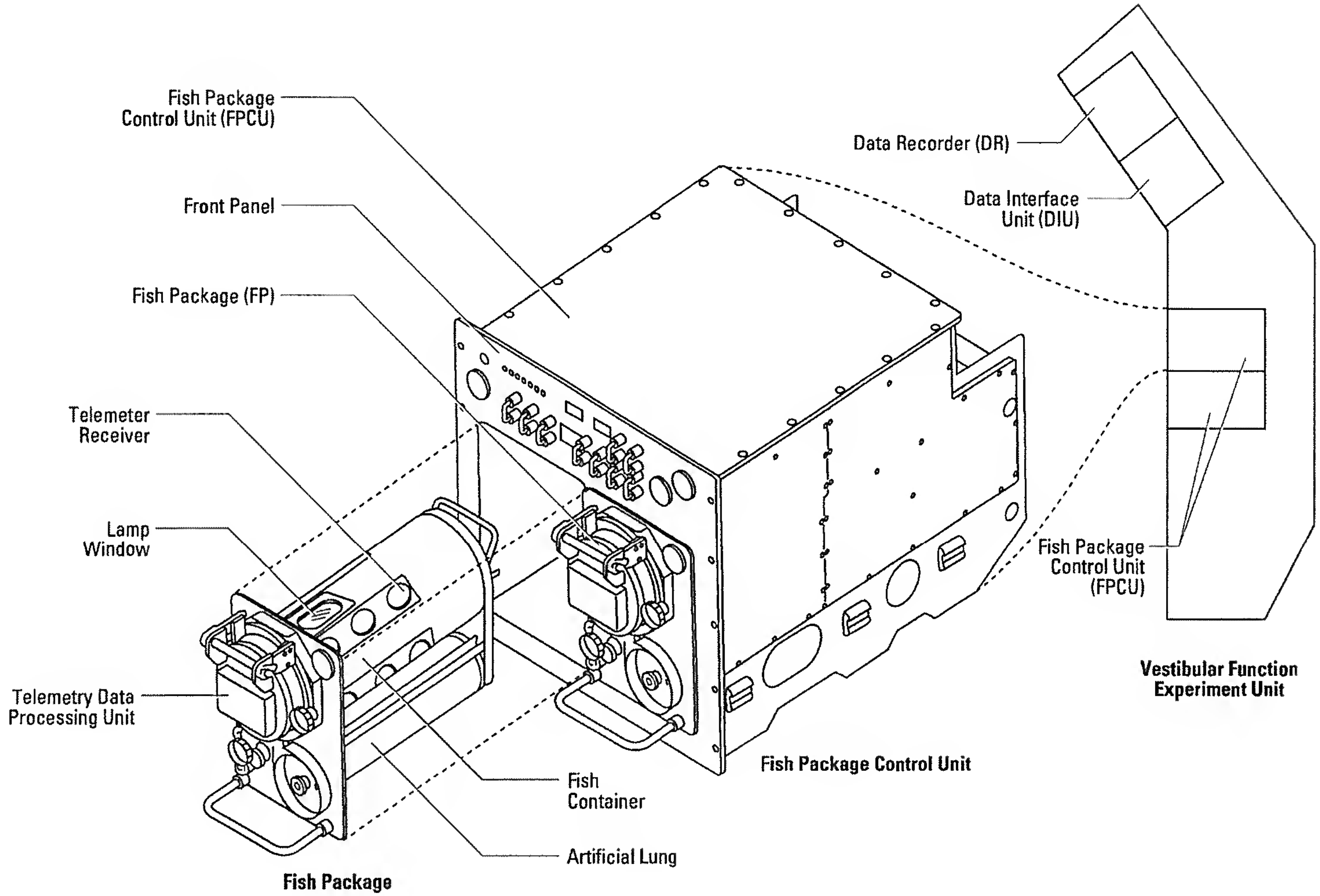

Figure 3.11 Vestibular Function Experiment Unit

To minimize design errors and downstream changes, the Neurolab Stowage team initiated a practice of meeting twice weekly with representatives of Science, Operations, and Crew Training to review designs before they were released for fabrication. The end result was that Neurolab flight stowage kits had very few redesign or hardware rework actions during the flight fabrication process. This was a significant accomplishment, which saved much needed time and resources.

3.2.13 Ground Support Hardware

Ground support hardware was all non-flight equipment that was required to enable assembly, integration, and test of the ARC Neurolab payload. The ground hardware interfaced with flight hardware for verification assessments and functionality demonstrations. It included equipment used to handle, check, verify, and test flight equipment operation. Ground hardware included items developed by NASA and international partners and commercially available equipment. A listing of ground support hardware used on Neurolab is included in Attachment 1.

4.0 Payload Operations

4.1 Introduction

The conduct of ARC payload operations was a collaborative effort across all teams participating in the mission. Payload activities included preparation; logistics; ground support; crew training; data management; safety, reliability, and quality assurance; and preflight, inflight, and postflight procedures.

4.1.1 Teams and Responsibilities

Payload Manager — This individual had responsibility for overall payload budget; contract task order; management over engineering, science, and operations elements; payload management of all the engineering, science, and operations requirements; primary interface to all external interfaces (i.e. international partners, Mission Management, and HQ management responsible for Neurolab). Ultimate responsibility for the day-to-day detailed operations of the ARC NL payload rested on this individual.

Integrated Project Team (IPT) Lead — The IPT lead was the contractor support responsible for managing the contractor work force. In addition, this individual managed ARC's requirements to KSC.

Project Scientist — The Project Scientist had the responsibility for review, evaluation, development, and management of flight research experiments; grants management; interface with funding and science agencies and international partners; and management of support service science contractors.

Crew Training — The Crew Training team consisted of two staff members who were responsible for working with Operations, Engineering, and Science to train the crew to perform the experiments and ensure proper operation of the hardware inflight. The team was responsible for formatting all flight procedures to Shuttle standards.

Data Systems — The Data Systems team managed the collection and monitoring of data during ground test and flight operations. The group developed, validated, and supported software routines and hardware to enable data collection, analysis of flight hardware, and experiment data. The team managed the postflight distribution of data to investigators and provided technical oversight over the science data collection.

Engineering — The Engineering team consisted of the Engineering Manager, several hardware development engineers and the Stowage/EUE Engineering group, which consisted of 15 engineers. The Engineering Manager was responsible for coordination and identification of all power, data interface, structural, and thermal issues for integration of the ARC payload, while other engineering staff was responsible for the concept design, drawings, and fabrication/ modification of all hardware (or experiment unique equipment).

The Stowage/EUE Engineering group was responsible for labeling all hardware and cables, and designing KC-135 prototype and flight-like hardware, crew training hardware, mockup hardware, and fit check hardware for cold stowage and vertical access simulations. The Stowage group was

responsible for reviewing JSC stowage drawings, lists and photos, and integrating the JSC mockup. The group coordinated and assured accuracy of the stowage list, early/late access requirements, and coordinated with Crew Training for providing input into the proper placement of stowed hardware both in the Middeck and Spacelab. They also dealt with refrigerated stowage and trash.

Payload Test & Integration — The Payload Test & Integration team was responsible for payload hardware processing and test and deployment to KSC, as well as oversight of integration and hardware preflight/postflight processing at ARC and KSC. In addition, the team was responsible for build, kitting, and integration of all stowage items.

Science — The Science team consisted of the NASA Project Scientist, Payload Scientist, Deputy Payload Scientist, Mammalian Development Team Lead, Neuronal Plasticity Team Lead, 11 Experiment Support Scientists (ESSs), Data Management Coordinator, and two data assistants as well as temporary staff to support activities requiring increased manpower, including data collection, data integration, birthwatch shifts (observation of dams and presence of births), litter equalization operations, litter selection (selecting animals based on date and time of birth, weight, and sex), collection of data, and data entry. The Payload Scientist ensured the implementation of approved requirements necessary to achieve the goals and objectives of approved flight experiments. The Payload Scientist was also the primary point of payload science authority and contact during experiment development, testing, and flight. The Deputy Payload Scientist was the backup to the Payload Scientist and delegated specific authorities and responsibilities, as required. Team leads were assigned to the Neuronal Plasticity and Mammalian Development disciplines, who were responsible for coordinating the experiments to meet the team objectives. The Team Lead ensured that the experiments were integrated and dealt with any conflicts among investigators regarding team experiment operations. The ESSs provided direct interface with Principal Investigators for all approved proposal objectives during definition, development, and implementation. Each ESS acted as a liaison between the PI and the Project team.

Science Logistics — The primary role of the Science Logistics team was to work with the Science team and the PIs to develop a Logistics Integrated Requirements Document (LIRD). The LIRD identified facilities, equipment, supplies, and services required for all pre- and postflight experiment processing at KSC and Dryden Flight Research Center (DFRC). The Science Logistics team was also responsible for coordinating lab readiness based on the requirements documented in the LIRD.

Safety, Reliability, & Quality Assurance — The Safety, Reliability, & Quality Assurance team was responsible for adherence of all ARC procedures and hardware to all NASA safety and quality assurance requirements. They represented both flight payload elements and KSC ground processing, from a safety perspective, to the Payload Safety Review Panel (PSRP).

4.2 Payload Preparation

Preparations for the mission consisted of activities such as planning, documentation development, testing, and reviews. Engineering, Science, and Operations groups all contributed to the development of the payload, as described in the Overview section of this report.

4.2.1 Planning

The ARC Neurolab Payload team developed plans for tests, crew training, systems and science data management, shipping (biospecimens and hardware), scrub/turnaround (launch delay), and inflight contingencies. Contingency planning included developing several documents to preplan strategies for dealing with contingency or off-nominal situations in a timely and effective manner.

4.2.2 Documentation Development

Various teams helped develop documents that outlined plans and procedures to follow during preflight, inflight, and postflight payload activities. Documentation included Experiment Requirements Documents; Integrated Experiment Requirements Documents; planning documents; crew training manuals; safety reports; Integration Data Packages, which contained integration and interface data as well as certification documentation for each payload element turned over to KSC for integration and stowage; and the Logistics Integrated Requirements Document (LIRD). For Neurolab, KSC requested that operations and engineering requirements, which are usually documented separately, be included in the LIRD.

4.2.3 Testing

A number of tests were conducted preflight to verify hardware function, science quality, and required operational activities. Tests included KC-135 flights; hardware verification flights (e.g. NIH.R3); the Experiment Verification Test (EVT), which was a simulation of the Neurolab mission, exercising preflight, inflight, and postflight payload operations, experiment, and hardware ground operations according to a baselined flight configuration; the Facility Trial Runs (Hangar L and Dryden); and ground studies, including a hypergravity study to serve as an analog to the microgravity studies. Planning for a flight duration of 16 days required the payload team to consider a 21-day duration. The additional days were to account for early loading and the possibility of two launch attempts and two weather wave-off days at the end of the mission. Tests were conducted for a 21-day-duration. Results of tests conducted by ARC are listed in Table 4.1.

Table 4.1. ARC Tests Supporting Science and Engineering Readiness for Space Flight

Date	Test	Results
December 1994	Launch/Landing Simulation (Acoustics & G-forces)	• Demonstrated no effect on maternal behavior, neonatal survival, or growth for Mammalian Development team • Demonstrated functionality of Hyperdrive electrode system for E100 experiment
May 1995	KC-135 Flight (E100 and E150 Behavior)	• Demonstrated feasibility of neonatal and adult rat behavioral experiments
January 1996	NIH-R.3 Hardware Verification Flight: Rat Neonate Housing	• Established minimum age (PN8) for rat neonates capable of being supported in existing hardware (11 day mission)
June 1996	Mammalian Development RAHF Biocompatibility Test	• Attempt to meet desired litter number (10) and maximum duration (21 days) • Animal condition posttest unacceptable • RAHF performance nominal
July 1996	Neuronal Plasticity RAHF Biocompatibility Test	• Telemetry implants and rat health marginal • Hyperdrive rats unable to access food • RAHF performance nominal

Table 4.1, continued. ARC Tests Supporting Science and Engineering Readiness for Space Flight

Date	Test	Results
August 1996	Repeat Mammalian Development RAHF Biocompatibility Test	• Litter number reduction to 8 acceptable • Animal condition acceptable (at 21 days) • RAHF performance nominal
September 1996	KC-135 Flight (Dissection and Behavior)	• Performed dissection flows for Mammalian Development and Neuronal Plasticity animals • Validated use of fixative vials and feasibility of tissue transfers between vials • Tested E150 apparatus design to meet science requirements
October-December 1996	Experiment Verification Test (RAHF 3 & 7) and Hypergravity Study	• All hardware functioned nominally (16 days) • PI pre- and postflight procedures implemented with no serious difficulties • Identified weak points of inflight procedures, developed recovery plan • Rodent food/water consumption below expected levels in all groups, re-test required • Unacceptable results for biotelemetry implant rats
March-April 1997	Mammalian Development RAHF Test	• Closed food/water issues from EVT • RAHF operated nominally (21 days)
April-May 1997	Neuronal Plasticity RAHF Test	• Closed food/water issues from EVT • Closed biotelemetry implant survival issues • RAHF operated nominally (17 days)
May 1997	AEM Filter Certification for Neurolab Mouse Experiment	• Demonstrated capability to contain odors for the intended Neurolab Nowakowski experiment (7 days)
July 1997	KC-135 (E100 Data Acquisition Hardware/Software Assessment)	• Successful collection of Hyperdrive data during all phases of parabolic flight
June 1997	Neonate AEM Biocompatibility Test	• Demonstrated capability to support 2 dams and 14 neonates aged 14 days for 21 days (load at L-19 hours, 2 launch attempts, 16 day mission, 2 weather wave-off days)
January-August 1997	AEM Access Lid, Holding Box, Transport Unit Certification (Ground & KC-135)	• Demonstrated capability to access mice, neonatal, and adult rats with Hyperdrive implants and transport
July 1997	VFEU Toadfish Biocompatibility Test	• Demonstrated capability to house toadfish and maintain fish health for planned mission duration (21 days)
July-August 1997	Hangar-L Facility Trial Run	• Verified Hangar L, SSPF, O&C facilities and procedures for pre-, in-, and postflight mission phases
December 1997	E150 and E100 Interface Verification Test	• Confirmed successful operation of video and electronic data acquisition hardware with the GPWS and inline Spacelab systems

4.2.4 Reviews

ARC Project and Mission Management reviews were required throughout payload development up until shortly before launch. ARC Project Status reviews provided management status of technical progress, problems, planned corrective actions, accomplishments, upcoming events, and science activities related to the payload. Formal ARC Project reviews included the Preliminary

Requirements Review, in which the initial payload design was formulated; the Preliminary Design Review, in which the design was reviewed and the hardware and stowage requirements were incorporated; the Critical Design Review, in which the design was finalized and confirmation to proceed with building/modifications of flight hardware and stowage was given; and Integration Readiness Reviews, in which hardware readiness for integration and shipment to KSC was assessed. Mission reviews included the Integrated Payload Reviews, Flight Planning and Stowage Review, Payload Readiness Review Flight Readiness Reviews, and Flight and Ground Safety Reviews. ARC also supported a scientific readiness review by the Associate Administrator at HQ.

4.2.5 Science Logistics

Logistics activities included coordination of requirements for payload tests and operations. For Neurolab, science logistics was supported by the Science Logistics team, while engineering logistics, scheduling, and coordination responsibilities were shared among other groups but coordinated by Operations. Science Logistics worked with PIs and the Science teams to create the Logistics Integrated Requirements Document (LIRD). The Neurolab LIRD contained almost 3000 line items. Science Logistics ensured that all items in the LIRD were provided in the amounts, timeframes, and locations specified. This was accomplished by shipping items from the logistics inventory at ARC, purchasing items, and negotiating with the other centers for items available on site. The negotiation process with KSC involved that center converting the LIRD to its own document, the Ground Support Requirements Document (GSRD).

Science Logistics took the lead to apply a lesson learned from a previous payload. During another mission, several people were detained by KSC security for carrying government property across the center without proper paperwork. On Neurolab, Science Logistics worked with ARC management to provide a property pass service for all ARC payload team members to allow transport of flight and ground items between onsite KSC buildings. Although it was not in the initial scope of the Science Logistics team's activities, this process worked well and no one was stopped with insufficient paperwork.

4.2.6 Crew Training

ARC Crew Training followed the directives in the Life Science Division (Code SL) Crew Training Plan, which outlined a standard methodology applied to all SL training. Responsibilities included:

- Coordinating (planning, scheduling, determining location) and conducting crew training sessions
- Monitoring crew performance using flight-like hardware and nominal procedures, allowing proper identification of either hardware and/or procedural-caused anomalies, and providing feedback to the project team on performance of hardware
- Evaluation of training and associated hours spent on training exercises; scheduling additional training with Mission Management Crew Training personnel
- Coordinating with Science to make changes to the Mission Science Requirements Document
- Tracking hardware changes that may or may not be reflected in training hardware
- Maintaining proper configuration and fidelity of stowage within the JSC mockup

- Relaying to crew any concerns and/or constraints the PIs and/or the payload may have on operations and their implementation.

Planning activities included developing documentation, such as familiarization manuals, nominal procedures, malfunction procedures, and science contingency procedures. The schedule for the preliminary drafts to the release of the final version of the draft and ongoing updates ranged from Launch minus 28 (L-28) to L-3 days. Arrangements were made with the international partners (NASDA and DARA) to provide training hardware to ARC and JSC that allowed for operational training.

Crew training for the ARC payload began in October 1996 and continued until two days prior to flight and was held at ARC, JSC, KSC, and various Principle Investigator (PI) labs throughout the U.S. The training consisted of a building block approach with timed phases: orientation, task, phase, proficiency, and mission integrated.

Orientation Training — Hardware and Experiment Orientation Training, conducted in October, 1996 at ARC, was intended to introduce each of the Neurolab ARC flight experiments to the Neurolab crew (flight and payload crews). It consisted of a two-day training session at ARC, which included hardware and science overviews and demonstrations. The crew received some hands-on introductory task training on some of the major hardware elements such as the General Purpose Work Station (GPWS), Vestibular Function Experiment Unit (VFEU), Research Animal Holding Facility (RAHF), Inflight Refill Unit, and some experiment kits. Experiment science orientation training was conducted at ARC but was presented when possible by the PI or with PI approval by the Payload or Deputy Payload Scientist. The crew was exposed to approximately two hours per hardware element and approximately 30 to 45 minutes per experiment. The experiments were numerous and the crew time limited so the hardware and science lectures were precise overviews. Detailed scientific papers were given to the crewmembers for reading on their own time. If the crew had specific questions they were emailed to ARC trainers who in turn contacted the PI. It was important to keep one point of contact between the crew and the PI. The crew worked a total of 21 hours during their two-day Orientation Training, including two-hour debriefing sessions at the end of each day.

Task Training — Task Training on the RAHF and GPWS was conducted along with Orientation Training. Task Training of other hardware elements and experiment kits was conducted at ARC during Task Training sessions. Task Training was designed to develop crew proficiency in all aspects of the experiment objectives through intensive and in-depth lectures on Experiment Unique Hardware and procedures, and through hands-on training with specimens and available hardware. Hardware task training included hardware maintenance and daily animal health checks, along with non-experiment specific hardware training. Specific activities included rodent dissections, neonate dissection, mouse injection and dissection, dexterity and video operations, the Escher staircase and magic carpet, BOTEX activation, VFEU manual acceleration, and recording and observation. The crew spent 36 hours on task training conducted primarily at ARC, but a few of the more intense experiment procedures were taught in the PI labs—mice injections and rat neonate muscle injections.

Phase Training — Phase Training was conducted at ARC and JSC over the course of several months (L-13 to L-9 months) to give the crew the opportunity to perform experiment repetitions so as to achieve a defined level of timed proficiency. Activities included participation in ARC timelined activities, ARC experiment lab training in mock-up and lab, and two KC-135 simulated microgravity sessions. A total of 80 training hours were dedicated to this portion of training.

Proficiency Training — This portion of the training was conducted at JSC and KSC during the L-9 months to L-1 day time frame. It was intended to enable the crew members to develop their proficiency to a level of performance where they could successfully perform all payload activities within the mission timeline. Activities included ARC experiment timeline training in a mockup, two sessions in the KC-135, and eight proficiency sessions conducted prior to Mission Integrated Training Simulations and Joint Integrated Training Simulations. Samples were sent to the PIs for evaluation and approval that the procedure was conducted in such a way to provide a sample to support the intended research. Training totaled 62 hours.

Mission Integrated Training — Mission Integrated Training, the final stage, allowed the Payload Operations Control Center (POCC) cadre at JSC and ARC to support rehearsal of the ground protocols conducted during flight. This training phase included the Mission Integrated Training Simulations (MITS) (5 simulations, with selected timeslices—portions of the inflight procedures), and Joint Integrated Training Simulations (3 simulations, with selected timeslices). All of these simulations were conducted at JSC with ground support at JSC and at ARC's Technical Monitoring Area. The MITS included timeline performance of all mission experiments and other activities necessary to carry out the mission. Each MITS occurred within a fully integrated Spacelab mockup and was supported by ARC training. Integration of the mockup began in March 1998. The crew logged approximately 32 hours during these simulations.

4.2.7 Data Management

Neurolab Data Management responsibilities were shared among different groups. Two general categories of data were collected for the payload: Systems Data and Science Data. Systems Data included hardware performance data and housekeeping data such as water delivery status and environmental data. Science Data included the project science data, managed and collected by ARC (such as water and food consumption); experiment-specific data, collected by investigators pre- and postflight; and inflight experiment data, collected by the crew and/or by various onboard data systems.

Data management for the ARC payload required an extensive development and coordination effort. In addition to identifying flight and ground data systems design requirements, the Data Systems team provided support during functional testing, biocompatibility testing, experiment verification testing at ARC, integration activities at KSC, and simulations at appropriate NASA centers.

The Science Logistics team assured that the data management groups had all the hardware and software needed. During the preparations for Neurolab it became clear that the hardware and software requirements for data collection, display, and summarization for visiting investigators would be complicated. Using facilities at KSC and DFRC, while dealing with computer support and firewall limitations, became a large effort. Science Logistics was asked to be the single point-of-contact for users with KSC and DFRC computer staff.

Science Data Management — The level of responsibility and involvement that ARC had in science data management varied across the specific teams. ARC developed a Data Management Plan for the project science data management activity for the rodent experiments across the Neuronal Plasticity (NP) and Mammalian Development (MD) teams, but was not responsible for data management plans for the Aquatic and Neurobiology teams. These were developed by the PIs within those teams. The Science Data Management group refers only to the personnel within

the ARC Science Team that coordinated the project science data management activities for the NP and MD teams.

The ARC Data Management Plan detailed the logistics and operations required for the collection, analysis, reduction, distribution, and archiving of rodent data collected during the preflight, inflight, and postflight periods and during all supporting activities. The plan was developed in coordination with the Science Data Management group with technical support from the Neurolab Data Systems Team, the Payload Test & Integration Team, and the ARC Data Archiving Project to ensure electronic and format compatibility. Figure 4.1 shows the phases of that data management activity.

Science data management activities are described in the preflight (Section 4.3.3), inflight (Section 4.4.2), and postflight (Section 4.5.2) Science Operations sections.

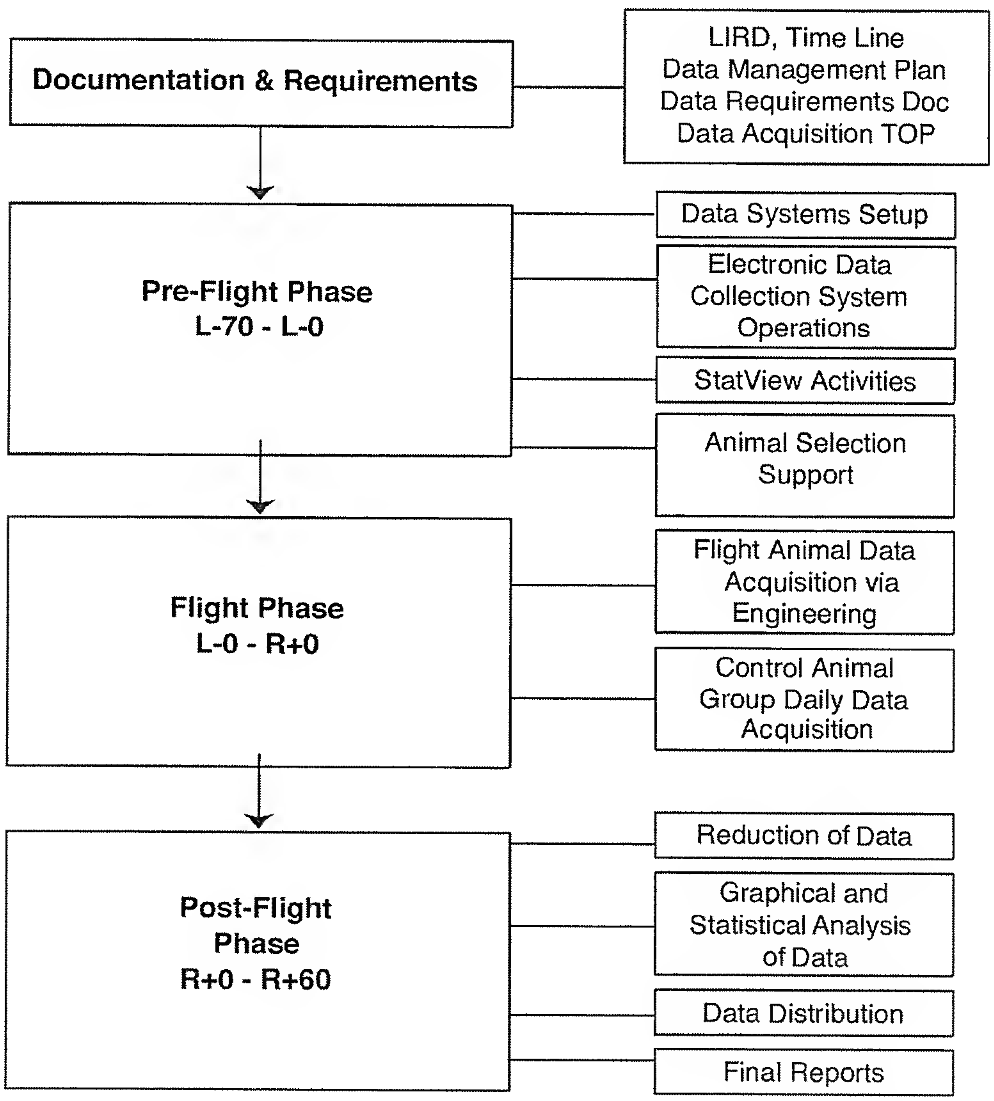

Figure 4.1. Project Science Data Management Activities for Neuronal Plasticity and Mammalian Development Teams

4.3 Preflight Operations

ARC occupancy at Hangar L at KSC began January 19, 1998 at L-3 months, with different teams arriving at various times. The ARC Payload team was at Hangar L to participate in final crew training, tests, and reviews; process hardware (from receipt to integration into the Spacelab); support science operations (from lab setup to animal receipt to loading of animals in habitats); and perform science data collection and analysis.

4.3.1 Test and Integration Activities

Test and Integration activities began at KSC after ARC shipped the hardware (time constrained hardware was shipped at approximately L-3 months).

An Operations Flight and Ground Support Hardware Processing team arrived at KSC at L-24 days. This team was responsible for flight, ground support, and ground control hardware receipt, inspection, and testing to ensure proper functioning. Once the hardware proved to function correctly, ARC turned it over to KSC engineering staff who then integrated the hardware into flight racks and performed various hardware checks, with ARC support. After checking to ensure that the hardware functioned in the racks, KSC integrated the racks into the Spacelab and then into the Shuttle. The ARC Test and Integration and Engineering teams were on hand to support this final integration process. The teams also supported RAHF and AEM cage preparations, checkout, animal loading, and turnover and provided support for the international partners hardware teams on the VFEU, BOTEX, and CEBAS.

Late Access activities included loading of time critical stowage, passive freezers, animal containing units, and cages into the Spacelab. The Spacelab was loaded at L-30 hours and the Middeck was loaded at L-18 hours. In addition, extensive support was provided to set up, operate, and maintain ground control hardware at KSC.

4.3.2 Data Systems

At L-3 days, ARC Data Systems engineers were at the KSC Operations & Checkout (O&C) building. The team supported the Mission Management team in the Launch Control Center to begin preflight data operations. After animals were loaded into the Shuttle (~L-20 hours), the Mission Management team sent commands to the ARC-developed Discrete to Serial Interface (DSTI) Unit. This on-pad interface unit relayed signals via the orbiter T-O umbilical cable onboard systems to the Spacelab. These commands were to:

- Place the RAHF into low power mode prior to launch
- Start the Data Recorder (DR) on the VFEU experiment hardware

Data from the DSTI allowed monitoring of temperatures, pressure, and on/off signal status via ground computer systems located at KSC's O&C building and at ARC's Test Monitoring Area (TMA).

4.3.3 Science Operations

Preflight science operations began with arrival of the Science discipline teams at KSC about L-90 days, followed by lab set-up, animal receipt, animal testing, implanting animals, animal selection and assignment of launch groups, and animal loading into the habitats according to preflight timelines. The Science Logistics team provided on site support to deal with last minute problems or changes. A one-day mission delay required unloading some of the animals and loading with the launch contingency groups.

Project Science Data Management — The Science Data Management group arrived at Hangar L, the Life Sciences Support Facility at KSC, at L-90 days to begin preflight operations, which included computer systems set-up, animal receipt, and acquisition of data using the Electronic Data Collection Systems (EDCS).

Animal receipt operations for the NP and MD rodents, beginning about L-74 days, included acquisition of initial food, water, and weight data. Data were immediately acquired and then transferred to a location at KSC where integration, report generation, and further processing could take place using the Electronic Data Analysis System (EDAS). Routine data collection (food, water, and body weight) occurred at 1-3-day intervals. After collection, data were passed on to the data integration station.

Data reports were generated on a daily basis during the mission to track the health and well-being of animal groups. The Science Data Management group produced daily reports, summary reports, and a comprehensive set of Mammalian Development (MD) litter selection data products.

Neuronal Plasticity Team — The Neuronal Plasticity Science team personnel arrived at KSC at approximately L-80 days.

At L-74 days, 150 adult male Fischer 344 rats were received at Hangar L. Rats were singly housed in standard vivarium cages. Two contingency groups of 150 rats each were received 30 and 60 days later to support launch delays.

Twenty rodents of each animal receipt group were assigned to the E100 (McNaughton) experiment, while 130 rodents of each group were assigned to the Integrated Neuronal Plasticity experiments (INP group), which included the remaining four experiments (Fuller, Ross, Holstein, Pompeiano). Animals were certified to be Specific Pathogen Free (SPF) and underwent microbiological testing before receipt at KSC, upon receipt at KSC, and at L-5 days.

Daily health checks, food and water consumption, and body weight data were used to select animals for biotelemetry implants. From L-45 to L-20 days, INP group food and water consumption measurements were taken every third day, while body weight data was taken weekly.

Data operations for the animals in the McNaughton experiment were performed by the PI's team. Data collection included food and water consumption measurements and body weight.

From L-45 to L-38 days, 96 animals from the INP Launch and Launch Contingency Group 1 were implanted with biotelemetry transmitter units to record deep body temperature, heart rate, and activity without restraint.

At L-3 days, animals were assigned to three experiment groups: Flight (FLT), Vivarium (VIV), and Simulation Caged Controls (SIM). Ground control studies for the McNaughton experiment were conducted at the PI lab.

The INP FLT group was loaded into RAHF cages, which were then placed into the RAHF located in the Spacelab at L-40 hours.

The VIV animals were housed in vivarium cages and followed the same experiment protocol as the FLT group, but on a 48-hour delayed schedule.

The SIM animals were housed in cages that simulated the volume, airflow, and lighting of the RAHF cages. These controls also followed the same experimental protocol as the FLT group, but on a 96-hour delayed schedule.

Mammalian Development Team — The Mammalian Development Science team personnel arrived at KSC at L-23 days.

Mice: Mice at embryonic day 1 were received daily until launch starting at L-12 days. The PI collected body weights daily for the mice. Mice were selected on the morning of Shuttle loading, based on body weight gain. The animals were loaded into AEM units at approximately L- 28 hours to projected launch. Due to the launch delay of 24 hours, the initial set of mice was removed and a scrub contingency group was reloaded 18 hours prior to the rescheduled launch. Vivarium and SIM-AEM ground controls were processed on a 48-hour and 96-hour delay, respectively.

P13 group: Rat dams, each with seven female neonates were received at post-natal day 6 (PN6). Six families were received daily, starting at L-9 days until launch, and were individually housed. For the P13 group, food/water consumption data and dam and litter body weights were collected daily. Litters were selected based on food and water data and growth curves for each potential launch group. The P13 group was loaded into AEM cages on PN13. The litters remained in the Shuttle AEM during the 24-hour launch delay. Vivarium and SIM-AEM groups were processed on a 4-and 8-day delay, respectively.

P7 group: Pregnant rat dams were received at 15 days of gestation (G15); 48 dams were received daily starting L-17 days and were individually housed. Litter body weights, and food and water consumption were taken at PN2, PN3, PN4, PN5, and PN6. PIs selected primary and backup litters, and then finally the 12 litters to be loaded. The P7 group was loaded into flight RAHF cages late in the evening of PN6. The litters remained in the Shuttle RAHF during the 24-hour launch delay. Vivarium and Sim-RAHF groups were processed on a 4- and 8-day delay, respectively.

Aquatic Team —

CEBAS: Preflight operations for the one U.S. experiment conducted in the CEBAS (which also accommodated nine German experiments) were performed by the University of Bochum PIs and the OHB hardware teams. The teams performed all animal and hardware operations beginning L-22 days. Preparation for candidate selection began at this time. The purpose of the selection process was to produce animals at a specific age that could adapt appropriately to the CEBAS. Neither ARC nor Dr. Wiederhold was responsible for the preflight data collection or management. Data collected at L-5 days included animal weights, plant

weights, and water parameters of flight specimens and ground controls. All animal and plant samples were loaded into the module at L-5 days.

VFEU: A majority of the lab was set up during the Facility Trial Run in August 1997. Fish tanks had to be set up at L-8 months to allow biofilters ample time to be seeded with proper bacteria colonies. Set up was performed by NASDA, Co-Investigator Dr. Mensinger, and KSC and ARC ground personnel. All labs and associated equipment were ready prior to the PI team arriving at KSC.

Data collection for toadfish in the VFEU began at L-2 months and included nerve testing and recording. The data were used in part to select flight candidates and also, for the final four flight animals, to provide a baseline comparison to data collected inflight since the animals served as their own controls. Selection of the flight pool animals occurred at L-5 days. Selection was based upon nerve impulse testing with the PI-provided data acquisition system. The flight pool consisted of 14 fish. Each was hardwired to connect to the PI's data collection system. After establishing the flight pool, nerve pulses of candidates were tested 2-3 times a day until L-1 day.

Four implanted toadfish were loaded into the VFEU fish packages at L-4 days. Following loading, nerve impulses were recorded to verify functioning. On L-1 day, the loaded fish were re-verified.

Neurobiology Team — Animals were received from the PI's home institution in Germany and set up in a cricket colony at L-2 months and maintained during the preflight period. Surgical manipulations were performed on the 6th instar animals. Flight candidate selection was based on overall health of the animal, developmental stage (8-day-old eggs, 1st instar, 4th instar, and 6th instar), and recovery from surgical manipulations. Turnover of the animals for integration activities was at L-19 days. The following numbers of developmental stages were loaded into the BOTEX chambers: 750 eggs, 500 1st instars, 240 4th instars, and 80 6th instars.

There were no preflight data transfers necessary for the Neurobiology experiment, as data were generated exclusively as a result of postflight processing of flight and ground controls.

4.3.4 Science Logistics at Dryden Flight Research Center

In addition to ensuring that the preflight requirements in the LIRD were met, Science Logistics also managed the Payload Receiving Facility (PRF) at Dryden Flight Research Center (DFRC), which involved setting up the facility to allow limited processing in the event of a Dryden landing. A large effort was required to coordinate a charter plane to fly samples and personnel back to KSC as soon as possible in the event of a Dryden landing. The payload required a Launch + 2 day readiness, which meant that if the Shuttle landed at Dryden 48 hours after it launched, the PRF and charter had to be ready to support that effort. Readiness involved proper equipment and personnel on site at the PRF, but it also required the appropriate KSC staff for Shuttle unload. In addition, Science Logistics coordinated with Level 04 personnel to ensure that items for the ARC Neurolab component would be transported to the PRF as soon as unloaded from the Shuttle. The mission also required radiation safety personnel on site since some of the flight samples would be radioactive. Because DFRC did not have a Radiation Safety group, ARC was required to coordinate and provide personnel. All DFRC support was coordinated preflight and last minute confirmation was done on site.

4.4 Inflight Operations

Following launch, the ARC Payload team was reconfigured to provide mission support at KSC, JSC, DFRC, and ARC. At the ARC Test Monitoring Area (TMA), a team of personnel monitored the payload including representatives from Engineering for each stowage hardware element. ARC provided representation from payload management, science, and training, and coordinated NASDA management support to manage the ARC flight operations at the JSC Payloads Operation Control Center (POCC). At KSC, ARC Operations staff used a room for the International Partner Engineering teams, the ARC liaison engineer, ARC science support, and Principal Investigators. Several personnel provided the asynchronous ground control studies hardware support at Hangar L. During the mission, there was one person at Dryden to monitor mission activity, but in the event that the Shuttle would land there, between 10 and 20 additional support staff were prepared to support a landing contingency.

4.4.1 Data Systems

Inflight, systems and housekeeping data were telemetered to the ground and monitored. This included telemetry data from the RAHF, BOTEX and VFEU experiment hardware. Video Data for the E100 experiment were relayed to the ground and the PI assisted with the inflight experiment from JSC's Payload Support Room in Bldg 30. Spacelab Telemetry data were available at JSC, where ARC and NASDA management monitored the mission. These data were then sent to the O&C building at KSC and the TMA at ARC. ARC, DARA, and NASDA Engineering operations staff monitored mission activities at KSC, and Data Systems and Stowage operations personnel tracked crew activities at ARC. The TMA also supported ground activities at KSC for rodent control experiments. All commands to the systems onboard, such as placing the RAHF back in full power and starting and stopping the VFEU Data Recorder, originated from JSC's Mission Control Center.

4.4.2 Science Operations

Neuronal Plasticity Team — Table 4.2 shows the planned inflight operations for the Neuronal Plasticity experiments.

Table 4.2. Inflight Operations for the Neuronal Plasticity Experiments

Investigator	Flight Day	Inflight Operations
Ross	2	Integrated adult dissections, 4 rodents
	14	Integrated adult dissections, 9 rodents
McNaughton	4	Neural activity recording
	9	Neural activity recording
Pompeiano	2	Integrated adult dissections, 4 rodents
	14	Integrated adult dissections, 9 rodents
Holstein	2	Integrated adult dissections, 4 rodents
	14	Integrated adult dissections, 9 rodents
Fuller	2	Integrated adult dissections, 4 rodents
	14	Integrated adult dissections, 9 rodents
	All days	Biotelemetry

Inflight, data collected included water lixit counts from the RAHFs for NP adults, foodbar measurements, and environmental data. Table 4.3 summarizes the types of data collected for the different cage environments.

Table 4.3. Inflight Data Collection for Different Cage Environments

Cage Type	Food Measurement	Water Measurement
RAHF	Tape Pulls (1 cm = 8.2 grams)	Lixit Counts
Sim RAHF	Tape Pulls (1 cm = 8.2 grams)	Graduated Cylinder (mls)
Vivarium	Weight in grams	Weight in grams
AEM	Preflight & Postflight weight in grams	Data not available

The E085 (Ross) experiment team performed a basal dissection on the day of launch. Five implanted animals and five non-implanted animals were used.

The crew performed daily animal health checks and performed RAHF 7 feeder tape readings on FDs 1, 2, 9, 11, 13, and 14 and a RAHF 7 feeder cassette changeout on FD 7. Water usage was monitored on the ground by downlinked lixit count data.

For the INP experiments, the crew performed inflight light pulses and dissections on some animals. For the E100 (McNaughton) experiment, the crew performed behavior and neurophysiology recording sessions on FD 4 and FD 9. These activities were conducted in the GPWS, which required deployment and activation. For the dissections, the dissection kits were unstowed and set up in the GPWS. Animals were transferred from the RAHFs via a General Purpose Transfer Unit. Following each dissection, the crew cleaned the work area. After all dissection procedures for each session, the crew cleaned up, returned the cages to the RAHFs, stowed biosamples, and restowed the GPWS. For the E100 experiment behavior and neurophysiology sessions, the crew unstowed and set up the Escher Staircase and Magic Carpet equipment, transferred the rodents from the AEM via the Animal Transfer Unit, attached equipment, and placed each rodent on the hardware to perform behavioral tasks. Setup for these sessions took about one to two hours. After each rodent performed the tasks, the crew returned the rodents to the AEM, restowed the E100 hardware, and cleaned and deactivated the GPWS.

On FD 8, the Spacelab Recirculation Carbon Dioxide Removal System failed and if not repaired, the mission would be shortened. In preparation for a shortened mission, PIs developed a backup dissection plan, but there was no need to implement it.

Mammalian Development Team — Table 4.4 shows the planned inflight operations for the Mammalian Development experiments.

Table 4.4. Inflight Operations for the Mammalian Development Experiments

Investigator	Flight Day	Inflight Procedures
Shimizu	8	Integrated neonate fixative perfusions and dissections, 6 rodents
	15	Integrated neonate fixative perfusions and dissections, 6 rodents
Nowakowski	3	Injection of cell marker/anesthesia of pregnant mice/removal of fetuses
	6	Injection of cell marker/anesthesia of pregnant mice/removal of fetuses
Baldwin	n/a	(Collection of tissue and blood was performed during postflight dissections)
Riley	8	Integrated neonate fixative perfusions and dissections, 6 rodents
	13	Injection of nerve marker
	15	Integrated neonate fixative perfusions and dissections, 6 rodents

Table 4.4, continued. Inflight Operations for the Mammalian Development Experiments

Investigator	Flight Day	Inflight Procedures
Kosik	8	Integrated neonate fixative perfusions and dissections, 6 rodents
	15	Integrated neonate fixative perfusions and dissections, 6 rodents
Raymond	8	Integrated neonate fixative perfusions and dissections, 6 rodents
	15	Integrated neonate fixative perfusions and dissections, 6 rodents
Walton	6	Video of locomotor-related behavioral tasks
	8	Integrated neonate fixative perfusions and dissections, 6 rodents
	8	Video of locomotor-related behavioral tasks
	11	Video of locomotor-related behavioral tasks

Mice: All inflight and ground control operations were nominal. Half of the animals were dissected on FD 3, and the remaining animals were dissected on FD 6. Dissections and injections were performed in the GPWS during two sessions. During the first session, all mice were transferred to the GPWS. Injections and dissections were performed on half of the mice. The rodents that were not dissected were returned to the AEMs. During the second session, the remaining mice that had not been previously injected were injected with a radioisotope-labeled marker. All remaining mice were dissected. The crew cleaned up the GPWS and stowed equipment. VIV (vivarium) and SIM (simulated caged control) ground controls were performed on a 2-day and 4-day delay basis, respectively, at KSC.

P13 Group: All inflight and ground control operations were nominal. Inflight behavioral/video operations were performed on eight of the animals on FD 6 and FD 11 for the E150 experiment. The crew activated the GPWS, set up the Animal Walking Apparatus and the video cameras, transferred animals from the AEM to the GPWS, conducted dexterity tests on the neonates while they were videotaped for 10 minutes, and returned the animals to the AEM.

P7 Group: VIV and SIM ground controls, with VIV at 4-day and SIM at 8-day delays, were maintained at KSC.

As with the NP animals, water lixit count data from the RAHFs, foodbar measurements, and environmental data were collected.

On FD 1, 2, and 6 the crew performed scheduled feeder tape and visual checks and noted in their logbooks that animals appeared "ok." The crew had planned to perform dexterity/video operations for the E150 experiment. Delays in the timeline resulted in shortened session and only AEM animals were tested.

Cage 1 of the RAHF was pulled on FD 8 to perform scheduled perfusions/dissections, and no negative reports were given at this time. However, during the postflight Crew Debrief it was stated that two neonates had died and only six were perfused and dissected.

E150 (Walton) activities scheduled for FD 6 were rescheduled for FD 8 to follow the perfusions/dissections. When Cage 11 was removed for E150 experiment, only five of eight animals were determined to be suitable for procedures. All were reported to be dehydrated, and it was found that none could perform the behavioral tasks. The Payload Commander decided to terminate the experiment session at this point.

Subsequently, Cage 6 was pulled to comply with a FD 7 Replan Request. This request had been based on an observed decreased lixit count from 50 to 22 during the previous two days and an assessment of the lixit function was planned to follow the E150 experiment. In Cage 6, five neonates were found dead with evidence of dam-induced trauma. The on-orbit attending veterinarian and the NASA veterinarian agreed that an evaluation of all cages was warranted.

During the Replan Request following FD 8, it was learned that the crew had performed cage pulls and evaluations of animal conditions well into their pre-sleep activity time. It was reported that all mortality appeared to have occurred over a fairly short time period. Specifically, 38 neonates were reported to be dead (five had been euthanized), 19 were listed as "sick," and 39 were reported to be "healthy." Many of the neonates were provided with supplemental fluids. The mortality and morbidity seemed to be distributed among all but one cage; that is, all eight neonates in Cage 10 were reported to be "healthy." Dead animals were stowed in dissection canisters.

On FD 9, an approved Replan Request for the FD 6 E150 behavior session was implemented and Cage 11 was taken to the General Purpose Work Station. At this time, the condition of the neonates was reported unsuitable to conduct the experiment although no details were provided. At the conclusion of FD 9, the crew reported that one neonate was euthanized and stowed with the other dead animals, three were listed as "sick" and were provided fluids, but the majority of the remaining animals including the dams were listed as "healthy" and "doing well." A total of 42 neonates were listed as "healthy" at this time.

No reports from the crew were received on FD 10. On FD 11, a cage-by-cage status was received and crew comments indicated that continued attention was warranted. Gel-packs were added to all cages to mitigate the apparent dehydration; subcutaneous fluids were provided to some animals as well. Thirty-six neonates were classified as "healthy" at this time including the entire litter in Cage 10.

The crew provided status at the end of the day on FDs 12, 13, and 15. Most animals were described to be "alert, responsive, active, and look good" although, in a few instances some were labeled "urine-soaked, stunted, thin." The dam and litter of eight in Cage 10 continued to be listed as "healthy" with only one indication on FD 11 that they were "mildly urine-soaked, tails healing, otherwise healthy." Leg muscle injections were performed as planned on six of eight neonates from Cage 10 on FD 13. After the FD 15 scheduled perfusions of six neonates from Cage 10, the population labeled "healthy" was reduced to 31. Some continued to receive subcutaneous fluid supplements, and the crew moved neonates between cages to take advantage of those dams that seemed to be most actively caring for their young.

Aquatic Team — Table 4.5 shows the inflight operations for the Aquatic experiments.

Table 4.5: Inflight Operations for the Aquatic Experiments

Investigator	Flight Day	Inflight Procedures
Wiederhold	All	Video of system
Highstein	All	Collection of nerve firing and accelerometer data

CEBAS: Inflight data collected for Wiederhold's experiment in the CEBAS were temperature strip readings and video. Lamp, oxygen, water temperature, ambient temperature, pH, and pressure data were also recorded. Interior specimen compartments of the CEBAS were videotaped inflight. The crew identified the Mission Elapsed Time during the tape changeout to allow the ground control experiment to follow the same timeline as inflight operations.

Loading of the 5-day delayed Lab Module (LM) group was performed during the postlaunch period. The LM module was a high fidelity mockup that included the same features as the flight module. It was placed in the Orbiter Environmental Simulator (OES) in Hangar L, to expose ground controls to identical environmental parameters experienced by the flight group.

Lab set-up for animal and plant hatchery, snail crawling behavior operations, and hardware operations started at FD 13 of the mission.

As with the flight group, animal selection, hardware preparation, or module landing operations were performed by Bochum University and OHB; PI and ARC staff were not directly involved.

VFEU: The crew collected nerve firing data and performed manual acceleration procedures, which included sliding the fish packages in and out of the VFEU mainframe. The crew performed three additional manual accelerations to make a total of six for the mission. The data were recorded to an onboard data recorder and downlinked during these acceleration periods. On FDs 3, 6, 9, 12, and 15, the crew collected 5 cc of water with a syringe and placed at 4 °C for postflight analysis. Following air pump failures on Fish Packages 2 and 3, the crew performed two inflight Maintenance procedures to cross-duct air circulation across the artificial lung of the VFEU.

Neurobiology Team — On FD 1, specimen containers were transferred from Middeck stowage to the BOTEX Incubator, which contained microgravity chambers and a 1-G centrifuge, to provide an inflight control group. The crew opened the door to the incubator every three days for air exchanges; this activity was verified using the downlinked engineering data displays. On the morning of landing, the specimen containers were removed and were returned to Middeck stowage for immediate access and transport to the laboratory following landing.

The 24-hour delayed control samples were maintained for all four age groups in flight-quality CRIC containers housed in a ground BOTEX incubator. Ground procedures, including CRIC container transfers, BOTEX air exchange operations, and temperature and centrifuge synchronization were performed on a 24-hour delayed basis, based on downlinked data from the flight BOTEX.

4.5 Postflight Operations

ARC supported recovery operations at KSC with postflight hardware processing, including rack mounted hardware and stowage deintegration activities, hardware inspection (and acquisition of digital photos, when possible), identification, limited cleaning, return shipment processing, and conduct of postflight functional tests and servicing.

4.5.1 Data Systems

Monitoring continued at landing. After hardware deintegration, all digital data were retrieved, backed-up, and copies were transferred to investigators as pre-agreed. Engineering, Science, and Logistics shared the management of data distribution. Project Science Data, such as RAHF water lixit counts and environmental data, were distributed to the appropriate ARC Science teams and Science Data Management group, while experiment-specific data were distributed directly to the investigators.

4.5.2 Science Operations

Project Science Data Management — As with cage load operations, unload operations for the Neuronal Plasticity and Mammalian Development teams were fully supported by the Science Data Management group. At the close of mission operations, all data and meta data were aggregated and copied to the server and backed up on portable media. In addition to daily reporting during mission operations, a comprehensive R+30 day data report, which included all data collected through that point, was delivered to the Principal Investigators.

Neuronal Plasticity Team — The animals were unloaded from the RAHF and AEM cages. The attending ground veterinarian determined that all animals were in good health and suitable for postflight research activities. The E100 (McNaughton) animals were shipped to the PI lab for postflight recording. The INP animals were placed in appropriate lighting conditions. Five animals were dissected on R+1 and the remaining six were dissected on R+13.

Mammalian Development Team —

P13 Group: Dams and neonates were unloaded from the AEM. All animals were in good health. The neonates and dams were turned over to the investigator for dissection of a portion of the litter and behavioral testing through R+30 on the remainder. Vivarium and SIM litters followed the P13 timetable on a 4- and 8-day delay basis.

P7 Group: Animals were received at Hangar L approximately 6.5 hours after landing. MD PIs, as well as the NASA Veterinarian, KSC veterinarian, MD Team Lead, and KSC Animal Care Specialist were present. Surviving neonates were cold and wet at unload. Animals were dried with paper towels and placed on heating pads. PIs worked together to revise the tissue flow and modify requirements to equitably distribute tissues from the litters to meet primary science objectives. Ground flow was performed with a reduced number (27) of flight neonates. Dissections, perfusions, and behavioral tests were conducted on the neonates, as indicated in Table 4.6. Behavioral testing was performed on the selected group up until R+30 days, at which point the animals were then dissected. Vivarium and SIM groups followed the same procedures on a 4-day and 8-day delay basis.

Table 4.6. R+0 Flight Neonate Distribution

Category	Number	Origin
R+0 Hypothyroid (Baldwin Dissects)	4	All from Cage Slot 4
R+0 Euthyroid Fresh (Baldwin Dissects)	6	Cage Slot 1: 26.53 g M; 44.01 g M Cage Slot 3: 49.23 g M Cage Slot 6: 48.57 g M Cage Slot 10: 35.04 g F Cage Slot 12: 31.74 g F
R+0 Euthyroid Physiology (Raymond perfuses and dissects)	5	Cage Slot 1: 35.18 g F Cage Slot 3: 50.99 g M Cage Slot 5: 39.80 g M Cage Slot 9: 49.42 g M; 54.19 g M
R+0 Euthyroid Physiology (Shimizu physiology and dissection)	6	Cage Slot 3: 51.14 g F; 53.39 g M; 54.54 g M Cage Slot 5: 48.52 g M; 50.19 g M; 53.62 g M
R+30 Euthyroid Behavior/Physiology (Walton, Kosik)	6	Cage Slot 11: 40.22 g F; 42.63 g F; 57.02 g F; 52.04 g M; 55.43 g M; 61.78 g M
Total	**27**	

Aquatic Team —

CEBAS: Postflight procedures documented the steps required for animal turnover from the Bochum dissection team, behavioral video observations, and snail tissue fixation. Postflight operations continued up through R+12 days. Data collected included water, snail numbers, sizes, statoconia volume, and crawling patterns, weights of hornweed and swordtail fish, and juvenile swordtail fish numbers.

Immediately upon retrieval from the module, the snails were sorted by age. Once all snails were sorted, they were divided into groups that would designate them as either fixation or behavioral testing groups. Operations for both groups were performed simultaneously. Behavioral testing was performed up through R+3 for the flight group and R+8 for the LM group. Following behavioral testing, these snails were transferred to the fixation testing group.

Areas assigned to the snail fixation and behavioral testing operations were closed out on R+11 and R+12.

VFEU: When flight toadfish were unloaded from the VFEU, two (in Fish Packages 2 and 3) were found dead. Data for the surviving toadfish in the VFEU were collected at Florida Institute of Technology, where nerve impulses were recorded from implanted fish before they were euthanized. The PI team performed a necropsy on the two dead flight fish. The PI team left the majority of flight pool fish (those that were unimplanted) at KSC to facilitate reflight of the VFEU on STS-95. An analysis of inflight water samples was performed. Although not required for the science procedures, science personnel distributed inflight data recorder tapes to NASDA. After PI lab deintegration, which began two days prior to landing, ARC shipped PI hardware not needed to support the STS-95 flight back to various locations

Neurobiology Team — Postflight data collection was performed by the PI team. After unloading from the BOTEX, the number of live animals recovered was recorded. The animals were maintained at either 14 °C or 29 °C prior to use in postflight test procedures. Test animals were distributed into two groups: one group was tested within a few days and the other group was allowed to further develop under Earth's gravitational field. Additional activities included solution preparation and transfer of prepared samples to ARC shipping.

Shipping — Postflight activities also included an elaborate effort to ship collected tissues and animals to investigators. A total of 6527 samples in 120 biomailers and a total of 128 animals were shipped (reference Table 4.7). After the mission, the time allotted for shutdown of the labs and return of equipment and excess supplies to ARC was cut short. Shipment of biospecimens to investigators was handled by the Science team with Science Logistics providing the necessary supplies.

Table 4.7. Summary of Tissue Shipping

Shipping Method	Number of Tissues Shipped	Number of Biomailers Shipped
Ambient	2160	6
4°C	2999	99
-70°C	980	15
-196°C (Dry Nitrogen Shippers)	460	5
Total	**6527**	**120**

4.6 Lessons Learned

This mission included all the significant challenges experienced in previous dedicated life sciences Spacelab missions plus the new challenges of coordinating four science discipline teams, utilizing international flight hardware, accommodating a wide range of animal subjects, and significantly upgrading two ARC life support hardware elements for improved and expanded performance. Inevitably, there were many lessons-learned in the operations area, several of which are profiled by category below.

4.6.1 Payload Management

1. Observation: Due to schedule constraints, postflight last-minute operations for Neurolab were common.

Lesson-learned: For large, complex missions with fast-track schedules, the payload needs to be prepared to increase shipping expenses to ensure that hardware shipping processes are efficient and reliable.

2. Observation: Late selection of PIs, coupled with the flight immaturity of some experiments, resulted in some payload elements being finalized very late in the payload flow. For example, delays in final delivery of vendor-provided hardware and late identification of safety issues related to that hardware resulted in the finalization of the final stowage hardware configuration until shortly before the last crew bench review.

Lesson Learned: PI selection should occur early. Experiments should be evaluated for maturity and time to design and develop a 1-G experiment into a flight experiment. Experiment adaptation for flight requires a long design and development process

3. Observation: Flight experiment budgets were insufficient for several experiments, which had significant operations, crew training, and stowage development costs. These additional areas added significant development costs late in the mission.

Lesson-learned: Costing of proposed experiments should account for project design, experiment immaturity, and protracted testing.

4. Observation: The Neurolab schedule, budget and contractor staff availability was driven by factors outside the control of the ARC Payload team. These factors negatively impacted the ability of the team to manage efficient development of payload hardware and stowage, training and adversely affected team morale.

Lesson-learned: Payload development is inevitably managed within an environment where trade-off between schedule, budget, and staff expertise and number and technical feasibility must be made on an ongoing basis. It is important to have the resources available to augment in areas on the critical path.

4.6.2 Payload Development & Testing

Hardware function and associated operations procedures are rarely 100% successful when tested and evaluated. This is true on the ground when performed by hardware development and

procedures experts and especially true when conducted by crew trained to support multiple experiments in the challenging environment of space flight. Setting success criteria for experiments early in the operations phase is critical for determining when the hardware and procedures are adequate for use. Setting and documenting agreed-on criteria is complex since experiment success is a mix of hardware performance, subject adaptation and well-being, measurement and biosample quality and quantity, procedures adequacy, and more. Many PIs have never designed, developed, and conducted the complete experiment proposed to NASA and thus do not have success criteria data even for lab-type experiment systems. Furthermore, what may be easy to do on the ground may not be easy to do inflight and is compounded by the fact that time and resources must be shared.

1. Observation: Hardware tests with rodents (dams plus neonates) in the modified RAHF cage and partitioned AEM were judged close to 100% successful preflight based on testing on the ground and during brief periods of simulated microgravity on KC-135 parabolic flights as well as on the inflight experiment on NIH.R3 (STS-72). The inflight success with neonates in the AEM was similar to that seen on the ground but success for neonates housed in the RAHF was dramatically reduced.

Lesson-learned: Several differences in these cages are possibly factors in trying to explain the different results, none of which would likely be seen in either of the preflight test environments. Thus, extrapolations from ground test results to flight performance, especially in complex behavioral situations such as dam/neonate interactions, may be unreliable. The success of a dam/neonate cage insert in an AEM on the earlier NIH.R3 mission may have had less to do with the cage insert design than the fact that the animals were provided with much more gripping surface, no smooth metallic walls, and a lower airflow than in the RAHF cage.

2. Observation: Several PIs were asked to conduct preflight demonstration studies of their experiments on the ARC Center for Gravitational Biology Research (CGBR) animal centrifuge to demonstrate feasibility based on animal subjects experiencing a new gravity environment.

Lesson-learned: Centrifuge studies with dams and neonates showed a large variation in the ability of dams to adapt to the hypergravity environment and maintain normal maternal behavior toward their neonates. Thus centrifuge studies may not only provide another data point (hypergravity) to be compared with 1 G and microgravity, it may provide a good method for collecting observations or developing criteria in the selection process for dams.

3. Observation: As a result of the inflight neonate mortalities, a postflight documentation review of the preflight animal/hardware testing was undertaken. Great difficulty was experienced in identifying, let alone acquiring these documents.

Lesson-learned: ARC needs to ensure that test reports (even if in an abstract format) are prepared for key hardware/animal tests. There is need for an online, secure database that allows keyword searches to identify these reports and ideally, provides online access to these reports. A Bioengineering Database (BED) is now being developed by ARC to address this need.

4.6.3 Hangar L

1. Observation: Some Hangar L Facility preflight trial runs were cancelled due to lack of budget, personnel, and facility availability. In addition, some experiments were not ready to provide a useful Facility Trial Run (FTR) at the time of the planned FTR. Few windows of opportunity

decreased the number of potential FTRs, which meant fewer preflight opportunities to identify issues.

Lesson-learned: Trial runs at KSC, with Science, Engineering, and Operations support, provide a valuable opportunity prior to loading of late-access items, to identify any remaining problems in hardware and stowage items, and/or with ground procedures. In order to appropriately evaluate the team, facilities, and procedures involved in science ground processing, it is critical to have all the elements participating, as they would be for the mission. If this is not possible, then some reasonable grouping could be done. But the point to be made is that a FTR is a valuable learning experience and adds to the team's readiness to support the mission

2. Observation: The preflight period at KSC requires support and often on-site training by staff representing management, science, data, engineering, animal care, logistics, and overall operations. Facilitating effective coordination and communications among this group, whose makeup changes dependent on the activities supported, is a major challenge and was taken into consideration for planning during Neurolab.

Lesson-learned: As was done during Neurolab, assignment of clear responsibilities to staff leads (with backups) for the various teams over the pre/in/postflight period at Hangar L is essential for effective coordination. Effective communications can be greatly facilitated by knowing who the key contacts are for each area and using mobile phones with voicemail, email, and similar IT tools as is done daily at ARC.

4.6.4 Crew Training

1. Observation: Feedback from the crew on problems experienced during training was not adequately communicated to Engineering, Science, and the PIs. Crew trainers were too busy to organize, document, and transmit this information.

Lesson-learned: The involvement of representatives from Engineering, Science, and Operations is essential for clearly understanding crew problems and developing potentially effective and timely solutions. Engineering should be present whenever new or replacement items are presented to the crew for the first time. (In addition, it is critical to train the crew with items in the flight configuration.) The crew should have an opportunity early in the training program to train in PI labs when inflight dissections are required. More than two trainers are needed for training-intensive missions to support the crew and facilitate high-quality communications.

2. Observation: Crew involvement with developing flight hardware was inadequate and early training with high-fidelity functional units was insufficient to avoid the need to reconfigure hardware late in development to obviate inflight operational problems.

After the PI and the payload team have had an opportunity to evaluate the effectiveness of experiment unique equipment in the flight configuration and deemed it acceptable, then the crew should be allowed to evaluate the hardware in its intended operational mode. Only after this assessment is done, should the flight build commence.

3. Observation: The complex integrated inflight dissections were successful mainly because of dedicated work by the investigators, crew training, and science personnel who worked to develop an efficient, integrated dissection protocol. But the PIs felt that additional opportunities to train the crews in their own labs would have enhanced the training. Also, the crew felt that they could

have done an even better job on dissections and all procedures if additional crew members were trained as backups when unanticipated help was needed.

Lesson-learned: Include initial crew training in PI labs when inflight dissections or complex science operations are to be performed. Additional crewmembers should be trained as backup support to the prime crew, especially if complex procedures are to be conducted in the space flight environment for the first time.

4.6.5 Project Science Data Management

The exceptionally large-scale task of data collection, analysis, summarization, reporting, distribution, and archiving (continuing) was highly successful due in large part to a dedicated core team and significant planning. The use of computers, databases, and data summarization and reporting software tools were essential for handling peak data flow periods and the many requests for almost real-time data from various members of the ARC Science team on location at KSC.

1. Observation: Many ad hoc requests were made to the Science Data Management group for reports, tables, matrices, and graphs, and changes in defined data collection procedures were requested (by informal communications) during mission operations. Informal queries from various data users about data integrity or the dependability of the Electronic Data Collection & Analysis System were difficult to respond to quickly during on-going activities.

Lesson-learned: Configuration control procedures for data collection, analysis, and overall management need to be established. This includes assignment of a data manager for single-point contact, the continual availability of an informed software engineer, and clearly identified data products and data users. Email-based requests for data and distributions of data could help track and document this complex process. Also, a more structured method, such as an online database for logging requests, is needed for requesting changes in baseline data collection procedures.

2. Observation: In spite of some preflight concerns about utilizing and depending on computer-based data collection, analysis, display, and reporting systems at KSC, the EDCS and EDAS worked very well and produced excellent results.

Lesson-learned: The investment in upgraded computer workstations (rented) solved all initial data and communication problems at KSC. These tools are now routinely used in life sciences research labs and must be utilized in the demanding, fast track mission operations environment. Data management in the ISS era will be even more dependent on reliable computer/software systems.

5.0 Conclusion

5.1 The Final Spacelab Life Sciences Mission

Neurolab, the final Spacelab mission, was the largest, most complex dedicated life sciences mission ever flown by NASA. It was also the only Shuttle mission dedicated to a specific scientific discipline: neuroscience. From its inception, Neurolab was seen as a precursor to life sciences discipline-focused research on the International Space Station (ISS). In fact, one of the goals of Neurolab was to use the mission as a model for collaboration on many levels. Indeed, the mission was truly intercenter, interagency, and international. Neurolab had two NASA Payload Element Developers (Johnson Space Center and Ames Research Center); many international partners (the European Space Agency and the Canadian, French, Japanese, and German space agencies); and several domestic partners (including National Institutes of Health, National Science Foundation, and the Office of Naval Research). Six international Principal Investigators in addition to the U.S. PIs flew experiments and two international astronauts (one from Canada and one from Japan) joined the U.S. Shuttle crew. The science was managed collaboratively and the research subjects included human and a wide range of non-human organisms. Many of the experiments on the mission produced data of interest to future studies on the consequences of long-duration space flight on animal development and were precursors done on the ISS.

5.2 Ames Research Center Payload

The ARC payload featured the most diverse and largest number of research organisms, the largest number of investigators, and largest complement of habitats and experiment unique equipment flown on a Shuttle mission managed by ARC. The development and coordination of this complex payload was a major accomplishment and required an intensive, ongoing collaborative effort across the payload disciplines of management, operations, engineering, and science. In addition, many ARC center resources, such as the centrifuge facilities, the model shop, the engineering shops (i.e. flight hardware fabrication, structural analysis), the Safety and Quality organization, and the Animal Care Facility contributed to the success of this mission. It is anticipated that this level of complexity will be typical for many ISS increments.

Throughout the development and implementation of the Neurolab payload, ARC confronted a number of difficulties and challenges related to budget, staffing, and schedule. Yet, ARC staff performed beyond expectations, the crew did an outstanding job of supporting experiments and handling unanticipated inflight problems, the science teams collaborated real-time to adjust postflight measurements to optimize the overall science return, and the vast majority of the experiments showed a high level of success. The Neurolab mission demonstrated that complex, multi-agency, international missions like those to come on the ISS will require great flexibility on the part of all participants, much good-will and cooperation, tolerance of some inevitable failures, and dedicated teams of experienced staff to produce solid science results.

5.3 Lessons for International Space Station

It was projected that many of the challenges and lessons-learned from this mission would be applicable to the ISS. While some of the lessons from Neurolab are specific to the Space Shuttle environment, several will likely extend to ISS including:

- **Translation of lab experiments to the flight environment**
  One of the core challenges in payload development for life sciences experiments is the development of novel hardware and experiment methods that are compatible with microgravity. Ground-based testing with living systems under short-duration microgravity (e.g., KC-135 parabolic flights) and hypergravity (e.g., centrifuges) are very useful during development, but on-orbit verification will still be important. *Lessons-learned suggest that continued use of the STS during ISS visitations and other methods to support evaluation of new hardware and methods will be essential.*

- **Communication across multiple payload preparation and operations teams**
  It has been observed that communication across many support teams is a major challenge during the following: payload preparation and testing; crew training; and preflight, inflight, and postflight operations. As the mission approaches, this challenge increases due to a) expansion of size and composition of teams; b) distribution of teams to different locations; and c) the expansion of work hours per day and workdays per week. Changes in staff during this process can exacerbate this problem. *Lessons-learned suggest the need to a) minimize staff responsibility changes over time; b) utilize mobile communications tools; and c) utilize web-based tools to allow people to provide and check status remotely, on demand. For ISS payload development, ensure that high-quality communications are established early since this will become a critical need as an increment approaches.*

- **Hardware development and testing**
  The sharing of flight hardware developed by different space agencies, as on Neurolab, is projected to increase on the ISS along with an increasing, inevitable need for inflight servicing and maintenance. The need for development of agency-specific, experiment-unique equipment and custom stowage items will continue. *Lessons-learned suggest that for both new and reflown hardware this will require increased sharing of a) hardware test, verification, operation and maintenance documentation; b) sharing of hardware training documentation; and c) accommodation of inflight performance evaluation tests for basic functional verification in microgravity.*

- **Inflight and ground-based subject processing and conduct of experiment controls**
  The conduct of space life sciences research continues to require inflight and ground-based research subject processing and conduct of experiment control studies. *Lessons-learned suggest that on-going high-quality coordination between the inflight crew and the ground support teams will be required for this effort on the continuously operating ISS. Ideally, actual inflight experiment environments and schedules will be reflected in follow-on ground-based control studies. Innovations are needed to find a way to conduct these control studies in a cost-effective manner.*

- **Training crew and ground support staff for life sciences R&D**
  The increased collaboration between space agencies, federal agencies, and mission support teams will require cross-training, training on demand (inflight and ground), and other new

training methods. *Lessons-learned suggest that online, multi-media training tools and aids will be needed to support this expanding requirement for the ISS era.*

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7.0 Attachment 1: Ground Support Hardware

The following ground support hardware was used to support Ames Research Center's payload on Neurolab. The ground hardware is categorized by the flight hardware that it supported.

8.1 Testing & Integration Support Equipment

The **Load Bank** was required during ground processing at KSC for calibration and validation of Rack Power System after shipping.

The **Fixative Bag Test Fixture** was designed for acceptance testing of each flight fixative bag and clamp assembly.

The **MRS Brushing Tool** was used to orient the brushings relative to the Payload Mounting Panel on the Middeck Rack Structure (MRS) during integration into the Orbiter.

The **MRS Integration Fixture** was used to maintain the parallelism of the rails on the Middeck Rack Structure during integration into Orbiter and to facilitate handling.

The **Recirculating Chiller (Ground Cooling Cart)** (commercially available) supported functional testing of flight hardware and provided a continuous flow of cooling fluid at a constant temperature and volume.

The **Simulated Experiment Interface (SEI)** was used to simulate Spacelab/experiment interfaces, including acquisition of RAHF data, and simulation of onboard displays, control inputs, and error/exception reporting.

The **Spacelab Rack Power System** was used to simulate Spacelab-provided power during offline checkout activities.

8.2 Research Animal Holding Facility

The **Air Circulation Cart** was used to support the RAHF and GPWS by circulating/regulating airflow through the rack via avionics duct to cool experiment electronics.

The **Cage Checkout Box** was used to support preparation of rodent RAHF cages for launch during preflight operations including checkout of cage electrical circuits.

The **Cage Carrier Dolly** provided a platform for stacking MVAK Cage Carrier Containers.

The **Fill Cart Assembly** (commercially available) provided cooling water for the RAHF water reservoir during offline testing.

The **Garages** were handling devices used for transportation and protection of RAHF rodent cages during offline operations.

The **MPCS Tester (RAHF Emulator)** (commercially available) was used for functional testing of MPCS during offline checkout activities and provided electrical simulation of RAHF peripheral electronics.

The **MVAK Carrier** was used for lowering RAHF rodent cages into the Spacelab during MVAK operation.

The **MVAK Cage Carrier Container** was a blue cube that held two MVAK carriers and had a lexan window for viewing rodents within the cage carriers.

The **Rack Power System** was a rack mounted assemblage of electronics equipment used to simulate Spacelab provided power during offline checkout activities; it was used to support the RAHF and GPWS.

The **RAHF Air System Leak Test Equipment** (commercially available) was an airflow meter used during operations to verify airflow through the RAHF.

RAHF Base Assembly, Manifold Holding Fixture was a bracket for holding the RAHF Water Manifold.

The **RAHF Module Handling Dolly** provided a platform for handling of the cage module.

The **RAHF Water Sampling Tool** was used to take samples from RAHF drinking water for testing of contaminants.

The **Vacuum Tool Assembly** was a hand-operated pump designed to draw any entrapped air bubbles from the RAHF water lines; it was to be used only on a contingency basis after RAHF integration if leak alarm was indicated.

8.3 General Purpose Work Station

The **GPWS Handling Dolly** was designed exclusively for transporting the GPWS cabinet.

The **GPWS Leak Test Setup** was a gn_2 bottle at 500 psi minimum used as a pressure source for pressure decay test.

The **Leak Detector** (commercially available) was used to support GPWS cabinet leak source detection.

The **Leak Standard** (commercially available) was a standardized gas of known composition, material that expelled a gas to the atmosphere at a known rate; it was used for calibration of the leak detector.

8.4 Vestibular Function Experiment Unit

The **Cooling Unit** functioned as a life supporting equipment to maintain temperature of VFEU fish packages.

The **FP (Fish Package) Support Stand** supported the VFEU when not mounted in the vertical rack; it provided a structure to prevent damage to FPs and connecting hardware while allowing access to control panel.

The **FP Driving Unit** provided mounting in a vehicle for the FPs to be transported to and from the experiment processing facilities and provided life support needs for fish in the FP.

8.0 Attachment 2: ARC Stowage

The ARC payload on the Neurolab mission required nearly 500 total pieces of stowed hardware. The following Stowage List includes each of the 231 unique items used to support the ARC payload. These stowage items were supplied by ARC, NASDA, DARA, and MMO.

Neurolab ARC Stowage List 4/27/98

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (In/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2081A	ARC	100885-003	FEEDER KIT	12	4.12	23.13	7.61	3.58	10326.3	123915.5	L6N	L6N	L6N	MVAK (L-10 Days) EA (R+24 Hrs)
GS			MD FEEDER KIT Z.1		1.87	58.75	19.33	9.09						REFILL NP RAHF 3 23 5 X 8 5 X 4.75 FREE DIMS RAHF, LEMON YELLOW, BACKLESS FEEDER GO INTO THESE AFTER CHANGEOUT
2092	ARC	101085-002	TABLE, RESTRAINT	1	9.5	13.38	8.75	5.5	10551.8	10551.8	OH-12	OH-12	OH-12	
GS			RESTRAINT/WORK TABLE		4.31	33.99	22.23	13.97						GPWS INCLUDES SPARE VIAL CAPS
2078	ARC	100681-001	ANIMAL DISPATCHER ASSEMBLY	1	5.5	6.5	15.25	10	16243.7	16243.7	OH-12	OH-12	OH-12	
GS			ANIMAL DISPATCHER KIT		2.49	16.51	38.74	25.40						GPWS USED ON FD 2 & 14 WITH DISPATCHER BASEPLATE
2114A	ARC	5184-101-B-01	GP TRANSFER UNIT	1	3.15	11.0	4.5	9.5	7706.0	7706.0	L8E	L8E	L8E	
GS			GPTU		1.43	27.94	11.43	24.13						
2124	ARC	AD801-885D-M322-001	MODULE, PLUG- AIRFLOW BALANCER	1	6.15	8.42	7.5	10.75	11124.6	11124.6	L8E	L8E	L8E	
GS			CAGE PLUG		2.79	21.39	19.05	27.31						
2070	ARC	100507 -001	FACE MASKS ASSEMBLY	5	.14	5.25	5.25	3.0	1355.0	6775.0	L9U	L9U	L9U	
GS			MASKS		0.06	13.34	13.34	7.62						
2065	ARC	100506-004	SURGICAL GLOVES KIT	1	.48	8.0	7.5	.65	639.1	639.1	L9U	L9U	L9U	
GS			GLOVES (XLG)		0.22	20.32	19.05	1.65						STOW WITH FACE MASKS, VACUUM PACKED 15 PER KIT (EXTRA LARGE) MOVE QTY 1 TO MD BEFORE FD 3.
2073	ARC	100632-001	GPWS CLEANUP KIT	1	1.055	6.25	6.0	1.5	921.8	921.8	L8U	L8U	L8U	
GS			CLEANUP KIT, GPWS		0.48	15.88	15.24	3.81						STOW REFURB SUPPLIES WITH CLEANUP KIT. GPWS USED FD 2,3,6,8,11,12,13,14,& 15.
2076	ARC	100636-001	BAG ASMBLY, GAUNTLET, FRT PORT	8	.28	8.5	8.0	.53	590.6	4724.7	L9U	L9U	L9U	
GS		4/27/98 REVISED QTY 1	GAUNTLET, FRONT		0.13	21.59	20.32	1.35						STOW WITH SIDE GAUNTLETS, VACUUM PACKED
2075	ARC	100635-001	BAG ASMBLY, GAUNTLET, SDE PORT	8	.25	6.0	4.75	.66	308.2	2465.9	L9U	L9U	L9U	
GS		4/27/98 REVISED QTY 1	GAUNTLET, SIDE		0.11	15.24	12.07	1.68						STOW WITH FRONT GAUNTLETS, VACUUM PACKED
2126	ARC	AD801-885D-M333-529	KIT, SPARE TWO RING SOCK	5	.19	13.0	14.0	.375	1118.4	5592.1	L10U	L10U	L10U	
GS		4/27/98 REVISED QTY	TWO-RING SOCK (SPARE)		0.09	33.02	35.56	0.95						PRIMARY & SPARES
2097	ARC	101187-002	DISSECTION CANISTER ASSEMBLY	28	.46	3.0	3.0	8.0	1179.9	33036.3	R9M	R9M	R9M	EA (R+24 Hrs)
GS			DISSECTION CANISTER		0.21	7.62	7.62	20.32						STOW ALL IN ONE LOCKER IF POSSIBLE. GPWS INCLUDES SPARES USED ON FD 2, 3, 6, 8, 14 & 15 MMO NOTIFIED THAT FLIGHT CUSHION DRAWING COMPLETE
2106	ARC	101432-001	GPTU CAGE ADAPTER KIT	1	12.10	13.88	3.94	23.25	20835.8	20835.8	R10K	R10K	R10K	
GS			RAHF ADAPTER		5.49	35.26	10.01	59.06						2 ADAPTERS DISASSEMBLED AND STOWED AS A SINGLE UNIT
2062	ARC	X100053-003	KIT, CONDENSATE	2	3.0	11.0	10.5	5.5	10409.9	20819.8	L10U	L10U	L10U	EA (R+48 Hrs)
GS			CONDENSATE KIT		1.36	27.94	26.67	13.97						MASS FOR FILLED COND BAGS (1 5 lb EMPTY) EACH KIT HOLDS TWO CONDENSATE BAGS
2072	ARC	100509-001	WET WIPES ASSEMBLY	5	.336	4.0	4.0	1.5	393.3	1966.4	L8U	L8U	L8U	
GS			WET TOWEL (REFURB)		0.15	10.16	10.16	3.81						STOW WITH CLEANUP KIT; VACUUM PACKED, SPARES
2093	ARC	101086-001	GAUZE, REFURBISHMENT KIT	2	.26	6.0	2.13	2.25	471.2	942.4	L8U	L8U	L8U	
GS			GAUZE (REFURB)		0.12	15.24	5.41	5.72						STOW WITH CLEANUP KIT GPWS
2094	ARC	101098-001	TOWEL REFURBISHMENT KIT	8	.53	6.25	5.63	2.63	1516.5	12132.1	L8U	L8U	L8U	
GS			TOWEL (REFURB)		0.24	15.88	14.30	6.68						STOW WITH CLEANUP KIT GPWS
2101	ARC	101307-002	LEATHER GLOVES ASSEMBLY	3	0.29	10.0	1.0	6.0	983.2	2949.7	OH-12	OH-12	OH-12	
GS			GLOVES, LEATHER		0.13	25.40	2.54	15.24						GPWS USED ON FD 2, 3, 6 & 14
2068	ARC	100506-003	SURGICAL GLOVES KIT	10	.44	8.0	7.5	.56	550.6	5506.1	L9U	L9U	L9U	
GS			GLOVES (LG)		0.20	20.32	19.05	1.42						STOW WITH FACE MASKS, VACUUM PACKED 15 PER KIT. (LARGE) MOVE QTY 1 TO MD BEFORE FD 3

Neurolab ARC Stowage List

4/27/98

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2074	ARC	100634-001	BAG ASSEMBLY, WASTE DISPOSAL	2	.1	8.0	8.0	1.25	1311.0	2621.9	OH-12	OH-12	OH-12	
GS			WASTE, GPWS		0.05	20.32	20.32	3.18						GPWS USED FD 2,3,6,8,11,12,13,14, & 15.
2077	ARC	100638-001	BAG ASSEMBLY, SPARE VELCRO	1	.1	6.0	6.0	.375	221.2	221.2	L8U	L8U	L8U	
GS			VELCRO (SPARE)		0.05	15.24	15.24	0.95						STOW WITH CLEANUP KIT GPWS
2095	ARC	101140-001	RAZOR BLADE ASSEMBLY	1	.063	1.75	1.125	1.0	32.3	32.3	L8U	L8U	L8U	
GS			RAZOR BLADE DISPENSER		0.03	4.45	2.86	2.54						GPWS STOW WITH CLEANUP KIT
2064	ARC	100324-001	SHARPS CONTAINER ASSEMBLY	2	.55	3.0	3.0	8.5	1253.6	2507.2	L8U	L8U	L8U	EA (R+48 Hrs)
GS			SHARPS CONTAINER		0.25	7.62	7.62	21.59						MASS FOR FILLED CONTAINER (EMPTY WT IS .46LB) GPWS
2087	ARC	100901-001	INFLIGHT REFILL UNIT	1	33.0	15.37	14.21	9.47	33893.7	33893.7	MF28O	MF28O	MF28O	TC (L-2 MONTHS)
GS			INFLIGHT REFILL UNIT, IRU		14.97	39.04	36.09	24.05						PRIMARY, STOW NEAR POTABLE WATER SUPPLY
2089	ARC	100949-001	CLOSEOUT PANEL KIT	3	2.11	23.4	7.6	7.1	20691.4	62074.1	R10K	R10K	R10K	
GS			CAGE TRANSFER PANELS		0.96	59.44	19.30	18.03						USED FOR CAGE PULL
2090	ARC	100949-002	CLOSEOUT PANEL KIT (USED)	3	.15	12.0	8.0	0.625	983.2	2949.7	R10K	R10K	R10K	BAGS FOLDED IN HALF PLACED INSIDE USED CLOSEOUT PANEL BAG. RETURN CONFIG SAME AS CLOSEOUT PANEL KIT
GS			CAGE TRANSFER PANELS (USED)		0.07	30.48	20.32	1.59						
2125	ARC	AD801-885D-M333-514	KIT, RODENT CAGE RESTRAINT	2	.44	3.5	1.5	1.5	129.0	258.1	L8E	L8E	L8E	
GS			RODENT CAGE RESTRAINT		0.20	8.89	3.81	3.81						GPWS USED ON FD 6, 11, 15
2122	ARC	AD600-835C-M046	MANUAL BYPASS PLUNGER OPERATING TOOL	1	.084	6.0	.34	.63	21.1	21.1	L10U	L10U	L10U	
GS			MANUAL BYPASS TOOL		0.04	15.24	0.86	1.60						CONTINGENCY ITEM
2067	ARC	100506-002	SURGICAL GLOVES KIT	3	.41	8.0	7.5	.47	462.1	1386.3	L9U	L9U	L9U	
GS			GLOVES (MED)		0.19	20.32	19.05	1.19						STOW WITH FACE MASKS, VACUUM PACKED 15 PER KIT. (MEDIUM) MOVE QTY 1 TO MD BEFORE FD 3
2127	MMO	10104-20019-01	WET WIPE DISPENSER	4	.25	4.5	2.63	2.13	413.1	1652.4	L8U	L8U	L8U	
GS			WET WIPE DISPENSER		0.11	11.43	6.68	5.41						STOW HORIZONALLY IF POSSIBLE
2138	ARC	TBD	LOG BOOK, RAHF	2	.3	8.5	11.0	.38	582.2	1164.5	MF57H	MF57H	MF57H	EA (R+24 Hrs)
GS			LOG BOOK, RAHF		0.14	21.59	27.94	0.97						PLACE IN SAME LOCKER AS THE PFDF. MMO PROVIDES FINAL LOGBOOK TO ARC SPEC. ARC PROVIDES CLAMPS (100466) AND ULTRA FINE BLACK SHARPIE'S (102540-003)
2137	ARC	TBD	LOG BOOK, GPWS	1	.15	6.0	4.0	.38	149.5	149.5	MF57H	MF57H	MF57H	EA (R+24 Hrs)
GS			LOG BOOK, GPWS		0.07	15.24	10.16	0.97						PLACE IN SAME LOCKER AS THE PFDF. MMO PROVIDES FINAL LOGBOOK TO ARC SPEC. ARC PROVIDES CLAMPS (100466) AND ULTRA FINE BLACK SHARPIE'S (102540-003)
2100	ARC	101306-001	BRUSH MIRROR KIT	1	.5	11	4.5	1.1	892.3	892.3	OH-12	OH-12	OH-12	
GS			BRUSH/MIRROR		0.23	27.94	11.43	2.79						GPWS USED FD 2,3,6,8,11,12,13,14, & 15
2079	ARC	100858-001	SCISSORS, DISSECTION, ATTACHABLE	1	.12	5.0	2.13	.19	33.2	33.2	L8U	L8U	L8U	
GS			MEDIUM SCISSORS		0.05	12.70	5.41	0.48						STOW IN SAME LOCKER AS VACUUM PACK ITEMS, USED FOR UNSEALING.
2096	ARC	101180-001	APPLICATOR, COTTON TIP KIT	2	.063	6.5	3.0	1.0	319.5	639.1	L8U	L8U	L8U	
GS			COTTON SWABS (REFURB)		0.03	16.51	7.62	2.54						GPWS STOW WITH CLEANUP KIT. QTY NEEDED WILL BE VALIDATED AT EVT
2123	ARC	X100050-004	ASSEMBLY, CHANGEOUT BAG	3	.23	6.0	3.0	3.0.	884.9	2654.7	L8E	L8E	L8E	
GS			CAGE PLUG BAG		0.10	15.24	7.62	7.62						STOW WITH CAGE PLUG
2099	ARC	101247-001	BAG, SPAF DUCT KIT	1	1.8	16.5	7.75	4.5	9429.7	9429.7	L10U	L10U	L10U	
GS			SPAF DUCT KIT		0.82	41.91	19.69	11.43						CONTINGENCY ITEM
2088	ARC	101146-001	FLUID PUMPING UNIT	1	21.0	14.50	14.21	9.47	31975.2	31975.2	L10B	L10B	L10B	TC (L-2 MONTHS)
GS			INFLIGHT REFILL UNIT, IRU (SPARE)		9.53	36.83	36.09	24.05						CONTINGENCY ITEM, S/N 003 FOR FLIGHT

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2082B	ARC	100885-005	FEEDER KIT	10	4.12	23.13	7.61	3.58	10326.3	103262.9	L6K	L6K	L6K	MVAK (L-10 Days) EA (R+24 Hrs)
GS			NP FEEDER KIT Z.3		1.87	58.75	19.33	9.09						REFILL ADULT RAHF 7 23 5 X 8 5 X 4 75 FREE DIMS RAHF, FLOURESCENT PINK
2115	ARC	5818380-501	PRESSURE GAGE ASSEMBLY, AUXILLARY	1	1.5	8.0	8.25	2.63	2844.5	2844.5	L8E	L8E	L8E	
GS			RAHF PRESSURE GAUGE		0.68	20.32	20.96	6.68						STOW NEAR RAHFS. CONTINGENCY ITEM
2080	ARC	100858-001	SCISSORS, DISSECTION. ATTACHABLE	1	.12	5.0	2.13	.19	33.2	33.2	L9U	L9U	L9U	
GS			MEDIUM SCISSORS		0.05	12.70	5.41	0.48						STOW IN SAME LOCKER AS VACUM PACK ITEMS. USED FOR UNSEALING
2091	ARC	10105-10145-01	SPECIAL STOWAGE BAG	1	.6	7.6	7.1	2.0	1768.5	1768.5	OH-12	OH-12	OH-12	
GS			STOWAGE BAG		0.27	19.30	18.03	5.08						WILL BE USEG TO CARRY STOWEG ITEMS FROM LOCKERS TO THE GPWS
2105	ARC	5701783	CONDENSATE DUMP ACCESSORY	1	3.0	6.80	1.625	1.625	294.3	294.3	L10U	L10U	L10U	
GS			DUMP TOOL		1.36	17.27	4.13	4.13						CONTINGENCY ITEM
2107	ARC	101516-001	GPWS GRILL SCREEN, ASSEMBLY	2	0.25	8.0	5.0	0.5	327.7	655.5	L8U	L8U	L8U	
GS			GPWS SCREEN		0.11	20.32	12.70	1.27						GPWS
2108	ARC	101521-001	BAG ASSY, CONTINGENCY	2	.3	8.0	4.0	0.6	314.6	629.3	OH-12	OH-12	OH-12	
GS			CONTINGENCY BAGS (8 x 8)		0.14	20.32	10.16	1.52						CONTINGENCY ITEM
2026	ARC	A9SP-9501-M150-1	DATA COMPUTER ASSY (U8)	1	21.0	18.0	16.9	3.8	18942.8	18942.8	OH-11	OH-11	OH-11	EA (R+06 Hrs)
100		5/29/7 REVISED-COMMENTS	ESCHER DATA COMPUTER		9.53	45.72	42.93	9.65						(NP--McNaughton) Outside GPWS Sun Based computer S/N 004 FOR FLIGHT
2029	ARC	A9SP-9501-M608-61	ESCHER STAIRCASE	1	1.7	15.0	16.5	3.2	12978.6	12978.6	L9B	L9B	L9B	
100		2/5/98 DELETE-PART OF ESCHERKIT1	ESCHER STAIRCASE		0.77	38.10	41.91	8.13						(NP--McNaughton) GPWS USEG ON FD 4 & 9
2036	ARC	A9SP-9501-M200-1	INTERFACE BOX ASSY (U7)	1	24.0	16.6	15.7	6.0	25624.8	25624.8	OH-11	OH-11	OH-11	
100		5/29/7 REVISED-COMMENTS	ESCHER INTERFACE BOX		10.89	42.16	39.88	15.24						(NP--McNaughton) Outside GPWS S/N 004 FOR FLIGHT
2113	ARC	101585-001	WATER REFILL LINE, AEM	1	3.02	14.0	14.0	1.4	4496.6	4496.6	WINDOW SHADE BAG	WINDOW SHADE BAG	WINDOW SHADE BAG	TC (L-2 MONTHS)
GS			AEM REFILL LINE		1.37	35.56	35.56	3.56						(MD-Nowakowski. Walton) AEM MMO HAS CONCURREG STOWAGE IN WINDOWSHADE BAG
2111	ARC	100902-004	POWER CABLE, IRU	1	.858	10.0	12.0	1.6	3146.3	3146.3	OH-12	OH-12	OH-12	
GS			RAHF/IRU POWER CABLE		0.39	25.40	30.48	4.06						PRIMARY IRU
2109A	ARC	100902-005	INLET HOSE, IRU	1	1.012	10.0	12.0	1.70	3343.0	3343.0	MF28O	MF28O	MF28O	TC (L-2 MONTHS)
GS		5/29/7 MMO REVISED-LOCATION	HOSE ASSEMBLY, IRU INLET		0.46	25.40	30.48	4.32						IRU
2110A	ARC	100902-006	OUTLET HOSE, IRU	1	1.056	10.0	12.0	1.40	2753.0	2753.0	OH-12	OH-12	OH-12	TC (L-2 MONTHS)
GS			HOSE ASSEMBLY, IRU OUTLET		0.48	25.40	30.48	3.56						PRIMARY IRU.
2006A	NASDA	T5-24203	VFEU WATER SAMPLE KIT 1 ASSY	1	1.54	8.15	7.48	2.362	2359.6	2359.6	R9E	R9E	R9E	TC (L-2 MONTHS)
088			WATER SAMPLE KIT		0.70	20.70	19.00	6.00						(AO--Highstein) VFEU
2007	NASDA	T5-24204	VFEU WATER SAMPLE KIT 2 / WATER SUCTION KIT	1	1.98	8.15	7.48	2.362	2359.6	2359.6	R9E	R9E	R9E	TC (L-2 MONTHS)
088			WATER SUCTION/SAMPLE KIT		0.90	20.70	19.00	6.00						(AO--Highstein) VFEU PRIMARY & CONTINGENCY ITEM
2001	DLR	CEB-VID-724	HI -8mm CC VIDEO TAPE	20	.176	2.638	4.016	.787	136.6	2732.6	MF57O	MD	MF57O	EA (R+48 Hrs)
004F			VIDEO TAPE, CEBAS		0.08	6.70	10.20	2.00						(AO--Wiederhold) CEBAS Sony P5-120MP, Hi 8mm, 120minutes (in PAL format)
2046	ARC	102261-001	AWA KIT R	1	12.50	19.25	6.00	7.00	13248.9	13248.9	R8U	R8U	R8U	
150			AWA KIT		5.67	48.90	15.24	17.78						(MD--Walton) GPWS USED ON FD 6, 11, & 15 INCUDES BACKDROP, CALIBRATION CUBE, AND PEN
2044	MMO	SED33103757-303	HI -8mm CC VIDEO TAPE	18	.176	2.638	4.016	.787	136.6	2459.3	L3G	MD	L3G	EA (R+48 Hrs)
150			VIDEO TAPE, DEXTERITY		0.08	6.70	10.20	2.00						(MD--Walton) RAHF FD 6, 11, and 15 INCLUDES SPARES Used with MPE Orbiter recorder, Sony P6-120HMPX, Hi 8mm, 120minutes MMO provides tape. No ARC labels per Commander

Neurolab ARC Stowage List

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2141	ARC	102452-001	RAHF WATER SAMPLER KIT	2	1.4	12.0	12.0	1.2	2831.7	5663.4	L9U	L9U	L9U	
GS			RAHF WATER SAMPLER KIT		0.64	30.48	30.48	3.05						RAHF CONTINGENCY ITEM DIMENSIONS REFLECT LANDING CONFIGURATION
2139	ARC	TBD	LOG BOOK, VFEU	1	.15	6.0	4.0	.38	149.5	149.5	MF57H	MF57H	MF57H	EA (R+24 Hrs)
GS			LOG BOOK, VFEU		0.07	15.24	10.16	0.97						(AO-- Highstein)PLACE IN SAME LOCKER AS THE PFDF. MMO PROVIDES FINAL LOGBOOK TO ARC SPEC ARC PROVIDES CLAMPS (100466) AND ULTRA FINE BLACK SHARPIE'S
2135	ARC	TBD	LOG BOOK, CEBAS	1	.15	6.0	4.0	.38	149.5	149.5	MF57H	MF57H	MF57H	EA (R+24 Hrs)
GS			LOG BOOK, CEBAS		0.07	15.24	10.16	0.97						(NB-- HORN)PLACE IN SAME LOCKER AS THE PFDF MMO PROVIDES FINAL LOGBOOK TO ARC SPEC. ARC PROVIDES CLAMPS (100466) AND ULTRA FINE BLACK SHARPIE S
2135	ARC	TBD	LOG BOOK, AEM	1	.15	6.0	4.0	.38	149.5	149.5	MF57H	MF57H	MF57H	
GS			LOG BOOK, AEM		0.07	15.24	10.16	0.97						(MD--Nowakowski, Walton)PLACE IN SAME LOCKER AS THE PFDF MMO PROVIDES FINAL LOGBOOK TO ARC SPEC. ARC PROVIDES CLAMPS (100466) AND ULTRA FINE BLACK
2140	MMO	528-20084-3	MAGLITE	1	.4	6.	.75	.75	55.3	55.3	OH-12	OH-12	OH-12	
GS			MAGLITE		0.18	15.24	1.91	1.91						USED FOR HEALTH CHECK MISSION PROVIDED EQUIP
2039	ARC	A9SP-9501-M608-20	MICRO-DISKETTES KIT	1	.5	4.5	4.5	.5	165.9	165.9	MF57H	SL	MF57H	LL (L-18Hrs) EA (R+48 Hrs)
100		3298REVISED-P/N	ESCHER DISKETTE KIT		0.23	11.43	11.43	1.27						(NP--McNaughton) LOCATED WITHIN THE PFDF
2028	ARC	A9SP-9501-M608-74	ESCHER DATA COMPUTER POWER CABLE	1	0.6	8.0	3.0	2.5	983.2	983.2	L8B	L8B	L8B	
100		2598DELETE-PART OF ESCHERKIT6	ESCHER DATA COMPUTER POWER CABLE		0.27	20.32	7.62	6.35						(NP--McNaughton) outside GPWS
2134	MMO	SED33103348-309	RS232 DATA CABLE (9-9 PIN)	1	1.0	6.0	2.0	6.0	1179.9	1179.9	L8B	L8B	L8B	
GS		5297MMOREVISED-P/NLOCATION	INTERCONNECT CABLE/PGSC		0.45	15.24	5.08	15.24						RAHF CONTINGENCY OPS, MISSION PROVIDED EQUIP, MMO PROVIDE STOWAGE INFO. DIMENSIONS ARE CABLE COILED.
2121	ARC	A9SP-9701-M200-5	ASSEMBLY, RODENT HOLDING BOX, ANIMAL ENCLOSURE MODULE	3	1.13	8.21	5.63	4.10	3105.5	9316.6	N/A	?	N/A	
GS		2598DELETE-STOWED IN ATU	MOUSE HOLDING BOX		0.51	20.85	14.30	10.41						SUPPORTS AEM OPERATIONS. STOW IN ATU
2032A	ARC	A9SP-9501-M608-60	ESCHER GROUNDING STRAP	1	0.1	4.0	2.0	2.0	262.2	262.2	L9B	L9B	L9B	
100		27/98DELETE-PART OF ESCHERKIT1	ESCHER GROUNDING STRAP		0.05	10.16	5.08	5.08						(NP--McNaughton) GPWS
2040	ARC	A9SP-9501-M603-1	TOOL KIT ASSY	1	1.0	10.0	6.0	7.0	6882.6	6882.6	L9B	L9B	L9B	
100		27/98DELETE-PART OF ESCHERKIT1	ESCHER TOOL KIT		0.45	25.40	15.24	17.78						(NP--McNaughton) GPWS INCLUDES SPARE
2004	NASDA	T5-24206	VFEU STOPPER ASSY	1	.089	6.102	1.18	.984	116.1	116.1	R9E	R9E	R9E	
088			STOPPER		0.04	15.50	3.00	2.50						(AO--Highstein) VFEU
2005A	NASDA	T5-24202	VFEU WATER REFILL KIT ASSY	2	2.64	8.15	7.48	2.362	2359.6	4719.2	R9E	R9E	R9E	MVAK (L-60 Hrs)
088			WATER REFILL KIT (SEA WATER)		1.20	20.70	19.00	6.00						(AO--Highstein) VFEU 2 SEA & 2 FRESH WATER
2025	ARC	A9SP-9501-M608-12	ESCHER CAMERA (SPARE)	1	0.4	4.9	3.0	1.0	240.9	240.9	L9B	L9B	L9B	
100		2598REVISED-P/N,DWG TITLE	ESCHER CAMERA (SPARE)		0.18	12.45	7.62	2.54						(NP--McNaughton) GPWS SPARE
2034	ARC	A9SP-9501-M608-7	ESCHER HEADMOUNT INTERFACE (SPARE)	1	0.6	6.0	4.00	2.50	983.2	983.2	L9B	L9B	L9B	
100		2598REVISED-P/N	ESCHER HEADMOUNT INTERFACE (SPARE)		0.27	15.24	10.16	6.35						(NP--McNaughton) GPWS SPARE
2133A	ARC	102267-001	FEEDER REPLENISHMENT KIT X.1, FOODBARS	6	3.82	19.0	7.5	1.0	2335.2	14010.9	MF28K	SL	MF28K	LL (L-18Hrs) EA (R+48 Hrs)
GS		2598REVISED -LOC	FEEDER REPLENISHMENT KIT X.1		1.73	48.26	19.05	2.54						KIT CONTAINS 4 FOODBARS USED TO SUPPORT RAHF 3 FEEDER CHANGEOUT CONTINGENCY
2045A	ARC	102264-001	VIDEO POWER KIT U	1	9.33	16.5	13.0	5.0	17575.1	17575.1	L6B	L6B	L6B	
150			VIDEO POWER KIT		4.23	41.91	33.02	12.70						(MD--Walton) GPWS INCLUDE ITEMS (STROBE, PWR SUPPLY & CABLES) USED ON FD 6, 11, & 15
2086	ARC	100902-003	TETHER, IRU	1	.30	4.0	2.0	1.0	131.1	131.1	OH-12	OH-12	OH-12	
GS			IRU TETHER		0.14	10.16	5.08	2.54						PRIMARY IRU
2098	ARC	100902-001	ADAPTER, MANUAL, IRU	1	2.0	12.0	5.0	1.4	1376.5	1376.5	MF28O	MF28O	MF28O	
GS			WCS, IRU ADAPTER (MANUAL, CWR)		0.91	30.48	12.70	3.56						CONTINGENCY ITEM

Neurolab ARC Stowage List

4/27/98

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2065	ARC	100902-002	ADAPTER, POWERED, IRU	1	2.0	12.0	5.0	1.4	1376.5	1376.5	MF28O	MF28O	MF28O	
GS			WCS, IRU ADAPTER (POWERED)		0.91	30.48	12.70	3.56						IRU
2112	ARC	100902-004	POWER CABLE, IRU	1	.858	10.0	12.0	1.6	3146.3	3146.3	MF28O	MF28O	MF28O	
GS			RAHF/IRU POWER CABLE		0.39	25.40	30.48	4.06						IRU
2103	ARC	101309-002	TIMER ASSEMBLY	16	0.1	2.75	2.75	0.75	92.9	1487.1	L8U	L8U	L8U	
GS			TIMER		0.05	6.99	6.99	1.91						
2128	MMO	SED33103757-303	HI -8mm CC VIDEO TAPE	5	.176	2.638	4.016	.787	136.6	683.1	L3G	MD	L3G	EA (R+48 Hrs)
GS			VIDEO TAPE, AEM		0.08	6.70	10.20	2.00						AEM, USED TO TAPE ANIMALS INSIDE AEM MISSION PROVIDED EQUIP Sony P6-120HMPX, Hi 8mm, 120minutes MMO provides tape. No ARC labels per Commander
2003	NASDA	T5-52202	NDAS DR TAPE	35	.089	3.15	2.322	.67	80.3	2810.7	OH-03	OH-03	OH-03	EA (R+48 Hrs)
088			DR TAPE		0.04	8.00	5.90	1.70						(AO--Highstein) VFEU
2131A	ARC	102289-001	ALCOVE CLOSEOUT PANEL KIT Y	3	1.50	23.4	8.00	1.00	3067.7	9203.0	R10K	R10K	R10K	
GS			ALCOVE CLOSEOUT PANEL KIT		0.68	59.44	20.32	2.54						USED TO SUPPORT RAHF 3 FEEDER CHANGEOUT
2018	MMO	SED33103757-303	HI -8mm CC VIDEO TAPE	8	.176	2.638	4.016	.787	136.6	1093.0	L3G	MD	L3G	EA (R+48 Hrs)
100			VIDEO TAPE, ESCHER		0.08	6.70	10.20	2.00						(NP--MCNaughton) MISSION PROVIDED EQUIP Used with Orbite recorder Sony P6-120HMPX, Hi 8mm, 120minutes MMO provides tape No ARC labels per Commander
2015A	ARC	102203-001	RADIOISOTOPE KIT I.1A	1	.71	6.80	9.20	1.56	1599.3	1599.3	L8J 4°C	L8J 4°C	RAD TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
093		5/29/ REVISED LANDING LOCATION	RADIOISOTOPE KIT I.1A		0.32	17.27	23.37	3.96						(MD--Nowakowski) GPWS ISOTOPES, EMPTY ON LANDING USED ON FD 3 INCLUDES SPARES
2015B	ARC	102242-001	RADIOISOTOPE KIT I.1B	1	.46	3.27	9.20	1.62	798.6	798.6	L8J 4°C	L8J 4°C	RAD TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
093			RADIOISOTOPE KIT I.1B		0.21	8.31	23.37	4.11						(MD--Nowakowski) GPWS ISOTOPES, EMPTY ON LANDING USED ON FD 6 INCLUDES SPARES
2043A	ARC	102196-001	MICROSYRINGE KIT E	1	2.24	10.30	11.20	1.70	3213.7	3213.7	R9E	R9E	R9E	MVAK (L-60 Hrs) EA (R+48 Hrs)
122			MICROSYRINGE KIT		1.02	26.16	28.45	4.32						(MD--Riley) GPWS USED ON FD 13. INCLUDES SPARE
2156A	ARC	102199-001	PERFUSION FIXATIVE KIT G.1A	1	.82	6.12	9.20	1.57	1448.6	1448.6	L8J 4°C	L8J 4°C	TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
NCDE			PERFUSION FIXATIVE KIT G.1A		0.37	15.54	23.37	3.99						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8 REPLACES PERFUSION PBS KIT H 1A
2156C	ARC	102200-001	PERFUSION FIXATIVE KIT G.2A	1	1.1	7.51	9.20	1.78	2015.3	2015.3	L8J 4°C	L8J 4°C	TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
NCDE			PERFUSION FIXATIVE KIT G.2A		0.50	19.08	23.37	4.52						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 15 REPLACES PERFUSION PBS KIT H 2A
2016A	ARC	102203-002	BUdR KIT I.2A	1	.71	6.80	9.20	1.56	1599.3	1599.3	L8J 4°C	L8J 4°C	RAD TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
093			MARKER BUdR KIT I.2A		0.32	17.27	23.37	3.96						(MD--Nowakowski) GPWS USED ON FD 3 WAS 4° INCLUDES SPARES
2016B	ARC	102242-002	BUdR KIT I.2B	1	.46	3.27	9.20	1.62	798.6	798.6	L8J 4°C	L8J 4°C	RAD TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
093			MARKER BUdR KIT I.2B		0.21	8.31	23.37	4.11						(MD--Nowakowski) GPWS USED ON FD 6. INCLUDES SPARES
2155E	ARC	102197-001	PERFUSION ACCESSORIES KIT F.1A	1	1.5	9.50	8.25	2.54	3262.2	3262.2	L3B	L3B	TRASH	
NCDE			PERFUSION ACCESSORIES KIT F.1A		0.68	24.13	20.96	6.45						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2042	ARC	102241-001	CLOSURE KIT O	1	1.2	11.05	7.20	1.24	1616.7	1616.7	R9E	R9E	R9E	TC (L-2 MONTHS)
122			CLOSURE KIT		0.54	28.07	18.29	3.15						(MD--Riley) GPWS USED ON FD 13
2154A	ARC	102239-001	KIT O.1 ASSY	1	.57	6.47	7.20	.75	572.5	572.5	L2B	L2B	L2B	TC (L-2 MONTHS) EA (R+48 Hrs)
NCDE			ANESTHESIA KIT O.1 - KETASET		0.26	16.43	18.29	1.91						(MD--Riley, Kosik, Raymond) GPWS INCLUDES SPARES USED ON FD8
2144A	ARC	102208-001	MOUSE ANESTHESIA KIT K.1	1	.67	8.58	9.20	0.9	1164.2	1164.2	L2B	L2B	L2B	TC (L-2 MONTHS) EA (R+48 Hrs)
093			MOUSE ANESTHESIA KIT K.1		0.30	21.79	23.37	2.29						(MD--Nowakowski) GPWS CONTROLLED DRUG, USED ON FD 3 Includdes spares
2144B	ARC	102208-002	MOUSE ANESTHESIA KIT K.2	1	.67	8.58	9.20	0.9	1164.2	1164.2	L2B	L2B	L2B	TC (L-2 MONTHS) EA (R+48 Hrs)
093			MOUSE ANESTHESIA KIT K.2		0.30	21.79	23.37	2.29						(MD--Nowakowski) GPWS CONTROLLED DRUG, USED ON FD 6 Includes spares

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NL NO. EXP	RESP	PART NUMBER	DRAWING TITLE STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2013A 093	ARC	102214-001	FIXATIVE KIT 3 FIX KIT 3	1	1.35 0.61	10.0 25.40	9.20 23.37	1.32 3.35	1990.0	1990.0	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Nowakowski) GPWS INCLUDES SPARE, USED ON FD 3
2013B 093	ARC	102214-002	FIXATIVE KIT 4 TFR FIX KIT 4	1	1.35 0.61	10.0 25.40	9.20 23.37	1.32 3.35	1990.0	1990.0	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Nowakowski) GPWS INCLUDES SPARE, USED ON FD 3
2013C 093	ARC	102214-003	FIXATIVE KIT 5 FIX KIT 5	1	1.35 0.61	10.0 25.40	9.20 23.37	1.32 3.35	1990.0	1990.0	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Nowakowski) GPWS INCLUDES SPARE, USED ON FD 6
2013D 093	ARC	102214-004	FIXATIVE KIT 6 TFR FIX KIT 6	1	1.35 0.61	10.0 25.40	9.20 23.37	1.32 3.35	1990.0	1990.0	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Nowakowski) GPWS INCLUDES SPARE, USED ON FD 6
2149A NCDE	ARC	102218-002	FIXATIVE KIT 7 FIX KIT 7	1	1.23 0.56	8.40 21.34	9.20 23.37	1.12 2.84	1418.4	1418.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2149E NCDE	ARC	102222-001	FIXATIVE KIT 10 FIX KIT 10	1	1.06 0.48	10.00 25.40	7.20 18.29	1.32 3.35	1557.4	1557.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2149F NCDE	ARC	102224-001	FIXATIVE KIT 11 FIX KIT 11	1	1.89 0.86	10.60 26.92	9.20 23.37	2.2 5.59	3515.7	3515.7	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2149G NCDE	ARC	102218-004	FIXATIVE KIT 17 FIX KIT 17	1	1.23 0.56	8.40 21.34	9.20 23.37	1.12 2.84	1418.4	1418.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 15
2149I NCDE	ARC	102222-002	FIXATIVE KIT 19 TFR FIX KIT 19	1	1.06 0.48	10.00 25.40	7.20 18.29	1.32 3.35	1557.4	1557.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 16
2149J NCDE	ARC	102222-003	FIXATIVE KIT 20 FIX KIT 20	1	1.06 0.48	10.00 25.40	7.20 18.29	1.32 3.35	1557.4	1557.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 15
2149K NCDE	ARC	102222-004	FIXATIVE KIT 21 FIX KIT 21	1	1.06 0.48	10.00 25.40	7.20 18.29	1.32 3.35	1557.4	1557.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-80 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 15
2149L NCDE	ARC	102224-002	FIXATIVE KIT 16 FIX KIT 16	1	1.89 0.86	10.60 26.92	9.20 23.37	2.2 5.59	3515.7	3515.7	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs) (MD--Riley, Kosik, Raymond) GPWS USED ON FD 15
2011A 093	ARC	102191-001	DISSECTION POUCH ASSY, MOUSE ,A.1 DISSECTION KIT A.1-MOUSE	1	.43 0.20	7.50 19.05	4.32 10.97	1.3 3.30	690.2	690.2	L2B	L2B	L2B	(MD--Nowakowski) GPWS USED ON FD 3 & 6.
2057A CDE	ARC	102192-001	DISSECTION POUCH ASSY, RODENT, KIT B.1 DISSECTION KIT B.1-RODENT	1	.72 0.33	7.50 19.05	7.28 18.49	1.2 3.05	1073.7	1073.7	L2B	L2B	L2B	(NP--Ross, Pompeiano, Holstein, Fuller) GPWS USED ON FD 2 & 14
2058A CDE	ARC	102193-001	DISSECTION POUCH ASSY, RODENT, KIT B.2 DISSECTION KIT B.2-SCALPELS	1	.944 0.43	7.50 19.05	4.90 12.45	1.3 3.30	782.9	782.9	L2B	L2B	L2B	(NP--Ross, Pompeiano, Holstein, Fuller) GPWS USED ON FD 2 & 14 INCLUDES SPARES
2147A NCDE	ARC	102194-001	DISSECTION POUCH ASSY, NEONATE,C.1 DISSECTION KIT C.1-NEONATE/OP1	1	1.21 0.55	8.50 21.59	6.80 17.27	1.75 4.45	1657.6	1657.6	L2B	L2B	L2B	(MD--Riley, Kosik, Raymond) GPWS TOOLS, USED FD 8 & 15
2148A GS	ARC	102195-001	DISSECTION POUCH ASSY,SPARE, KIT D DISSECTION KIT D-SPARE	1	.64 0.29	7.50 19.05	6.58 16.71	1.5 3.81	1213.1	1213.1	L2B	L2B	L2B	GPWS SPARE, NOT EXPERIMENT SPECIFIC
2008A1 089	DLR	BTX-CR1a	CRIC1 CONTAINER CRIC1a	1	5.55 2.52	6.59 16.74	12.8 32.51	2.59 6.58	3580.1	3580.1	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs) (NB--Horn) BOTEX
2008B 089	DLR	BTX-CR2	CRIC2 CONTAINER CRIC2	1	1.66 0.75	13.0 33.02	2.36 5.99	5.04 12.80	2533.9	2533.9	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs) (NB--Horn) BOTEX

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NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2008C1	DLR	BTX-CR3a	CRIC3 CONTAINER	1	3.81	3.94	3.94	3.09	786.1	786.1	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC3a		1.73	10.01	10.01	7.85						(NB--Horn) BOTEX
2008D	DLR	BTX-CR4	CRIC4 CONTAINER	1	10.60	13.0	13.0	4.84	13404.0	13404.0	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC4		4.81	33.02	33.02	12.29						(NB--Horn) BOTEX
2155G	ARC	102197-002	PERFUSION ACCESSORIES KIT F.1B	1	1.5	9.50	8.25	2.54	3262.2	3262.2	L3B	L3B	TRASH	
NCDE			PERFUSION ACCESSORIES KIT F.1B		0.68	24.13	20.96	6.45						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2155F	ARC	102197-003	PERFUSION ACCESSORIES KIT F.2A	1	1.5	9.50	8.25	2.54	3262.2	3262.2	L3B	L3B	TRASH	
NCDE			PERFUSION ACCESSORIES KIT F.2A		0.68	24.13	20.96	6.45						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 15
2155H	ARC	102197-004	PERFUSION ACCESSORIES KIT F.2B	1	1.5	9.50	8.25	2.54	3262.2	3262.2	L3B	L3B	TRASH	
NCDE			PERFUSION ACCESSORIES KIT F.2B		0.68	24.13	20.96	6.45						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 15.
2154B	ARC	102239-002	KIT O.2 ASSY	1	.57	6.47	7.20	.75	572.5	572.5	L2B	L2B	L2B	TC (L-2 MONTHS) EA (R+48 Hrs)
NCDE			ANESTHESIA KIT O.2 - KETASET		0.26	16.43	18.29	1.91						(MD--Riley, Kosik, Raymond) GPWS INCLUDES SPARES USED ON FD 13.
2154C	ARC	102239-003	KIT O.3 ASSY	1	.57	6.47	7.20	.75	572.5	572.5	L2B	L2B	L2B	TC (L-2 MONTHS) EA (R+48 Hrs)
NCDE			ANESTHESIA KIT O.3 - KETASET		0.26	16.43	18.29	1.91						(MD--Riley, Kosik, Raymond) GPWS INCLUDES SPARES USED ON FD 15
2047A	ARC	102265-001	VIDEO SPARES KIT V	1	1.58	7.5	5.0	4.0	2458.1	2458.1	L6B	L6B	L6B	
150			VIDEO SPARES KIT		0.72	19.05	12.70	10.16						(MD--Walton) OUTSIDE GPWS USED ON FD 6, 11 & 15 INCLUDES E150 CAMERA, ZOOM LENSE & CONTIGENCY COMCORDER CABLES.
2048A	ARC	102262-001	CAMERA KIT S	1	2.48	13.0	6.0	4.0	5112.8	5112.8	L6B	L6B	L6B	
150			CAMERA KIT		1.12	33.02	15.24	10.16						(MD--Walton) OUTSIDE GPWS USED ON FD 6, 11 & 15 TWO CAMERAS ATTACHED TO BRACKETS AND LENSE HOODS.
2104A	ARC	101312-002	PEN ASSEMBLY	1	.1	6.25	.375	.375	14.4	14.4	L3G	L3G	L3G	
GS			PEN		0.05	15.88	0.95	0.95						STOW WITH LOGBOOKS AND IN ANY LOCKER WHERE THERE IS A REQUIREMENT TO RECORD DATA.
2104B	ARC	101312-002	PEN ASSEMBLY	1	.1	6.25	.375	.375	14.4	14.4	L3P	L3P	L3P	
GS			PEN		0.05	15.88	0.95	0.95						STOW WITH FEEDER KITS. MMO NOTIFIED THAT FLIGHT CUSHION DRAWING COMPLETE
2104C	ARC	101312-002	PEN ASSEMBLY	1	.1	6.25	.375	.375	14.4	14.4	L6N	L6N	L6N	
GS			PEN		0.05	15.88	0.95	0.95						STOW WITH FEEDER KITS. MMO NOTIFIED THAT FLIGHT CUSHIDN DRAWING COMPLETE
2104D	ARC	101312-002	PEN ASSEMBLY	1	.1	6.25	.375	.375	14.4	14.4	L6K	L6K	L6K	
GS			PEN		0.05	15.88	0.95	0.95						STOW WITH FEEDER KITS. MMO NOTIFIED THAT FLIGHT CUSHIDN DRAWING COMPLETE
2156B	ARC	102199-002	PERFUSION FIXATIVE KIT G.1B	1	.82	6.12	9.20	1.57	1448.6	1448.6	L8J 4°C	L8J 4°C	TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
NCDE			PERFUSION FIXATIVE KIT G.1B		0.37	15.54	23.37	3.99						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8 REPLACES PERFUSION PBS KIT H 1B
2156D	ARC	102200-002	PERFUSION FIXATIVE KIT G.2B	1	1.10	7.51	9.20	1.78	2015.3	2015.3	L8J 4°C	L8J 4°C	TRASH POUCH	MVAK (L-60 Hrs) EA (R+48 Hrs)
NCDE			PERFUSION FIXATIVE KIT G.2B		0.50	19.08	23.37	4.52						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 15 REPLACES PERFUSION PBS KIT H 2B
2149M	ARC	102218-003	FIXATIVE KIT 8	1	1.23	8.40	9.20	1.12	1418.4	1418.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
NCDE			FIX KIT 8		0.56	21.34	23.37	2.84						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2149N	ARC	102370-001	FIXATIVE KIT 9	1	.72	7.40	7.20	1.12	977.9	977.9	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
NCDE			TFR FIX KIT 9		0.33	18.80	18.29	2.84						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8
2149O	ARC	102370-002	FIXATIVE KIT 18	1	.72	7.40	7.20	1.12	977.9	977.9	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
NCDE			FIX KIT 18		0.33	18.80	18.29	2.84						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 15
2006B	NASDA	T5-24205	VFEU SAMPLE SYRINGE ASSY	1	.176	8.0	3.543	.984	457.0	457.0	R9E	R9E	L8J 4°C	EA (R+06 Hrs)
088			SAMPLE SYRINGE FD3		0.08	20.32	9.00	2.50						(AO--Highstein) VFEU Subassembly of T5-24203, FD3

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2006C	NASDA	T5-24205	VFEU SAMPLE SYRINGE ASSY	1	.176	8.0	3.543	.984	457.0	457.0	R9E	R9E	L8J 4°C	EA (R+06 Hrs)
088			SAMPLE SYRINGE FD 6		0.08	20.32	9.00	2.50						(AO--Highstein) VFEU Subassembly of T5-24203, FD6
2006D	NASDA	T5-24205	VFEU SAMPLE SYRINGE ASSY	1	.176	8.0	3.543	.984	457.0	457.0	R9E	R9E	L8J 4°C	EA (R+06 Hrs)
088			SAMPLE SYRINGE FD 9		0.08	20.32	9.00	2.50						(AO--Highstein) VFEU Subassembly of T5-24203, FD9
2006E	NASDA	T5-24205	VFEU SAMPLE SYRINGE ASSY	1	.176	8.0	3.543	.984	457.0	457.0	R9E	R9E	L8J 4°C	EA (R+06 Hrs)
088			SAMPLE SYRINGE FD 12		0.08	20.32	9.00	2.50						(AO--Highstein) VFEU Subassembly of T5-24203, FD12
2006F	NASDA	T5-24205	VFEU SAMPLE SYRINGE ASSY	1	.176	8.0	3.543	.984	457.0	457.0	R9E	R9E	L8J 4°C	EA (R+06 Hrs)
088			SAMPLE SYRINGE FD 15		0.08	20.32	9.00	2.50						(AO--Highstein) VFEU Subassembly of T5-24204, FD15
2104E	ARC	101312-002	PEN ASSEMBLY	1	.1	6.25	.375	.375	14.4	14.4	R10K	R10K	R10K	
GS			PEN		0.05	15.88	0.95	0.95						
2083A	ARC	100885-004	FEEDER KIT	12	4.12	23.13	7.61	3.58	10326.3	123915.5	L3P	L3P	L3P	MVAK (L-10 Days) EA (R+24 Hrs)
GS			MD FEEDER KIT Z.2		1.87	58.75	19.33	9.09						REFILL NP RAHF 3, 23 5 X 8 5 X 4 75 FREE DIMS RAHF. FLOURESCENT BLUE
2133B	ARC	102288-001	FEEDER REPLENISHMENT KIT X.2, REMNANT BAGS	6	.11	10.0	10.0	.20	327.7	1966.4	MF28K	SL	MF28K	
GS		4/27/98 REVISED::COMMENTS	FEEDER REPLENISHMENT KIT X.2		0.05	25.40	25.40	0.51						KIT CONTAINS 4 FB REMINANT BAGS. USED ON FD11 TO SUPPORT RAHF 3 FEEDER CHANGEOUT X 1
2163	ARC	102458-001	BLUE PAD KIT T	1	1.17	8.5	11.0	3.5	5362.7	5362.7	OH-12	OH-12	OH-12	
GS			BLUE PAD KIT		0.53	21.59	27.94	8.89						GPWS KIT CONTAINS RESTRAINT TABLE PADS.
2117	ARC	A9SP-9701-M001-1	ACCESS AND TRANSFER UNIT, ANIMAL ENCLOSURE MODULE	1	9.92	19.36	14.86	9.63	45399.6	45399.6	N/A	MF57M	N/A	
GS		5/29/97 DELETE::STOWED IN ATU	ACCESS AND TRANSPORT UNIT (ATU)		4.50	49.17	37.74	24.46						SUPPORTS AEM OPERATIONS INCLUDES GPTU (5184-101-8-01) SUBASSY OF STOWAGE CONFIGURATION. ATU
2011B	ARC	102191-002	DISSECTION POUCH ASSY, MOUSE ,A.2	1	.43	7.50	4.32	1.3	690.2	690.2	L2B	L2B	L2B	
093			DISSECTION KIT A.2-MOUSE		0.20	19.05	10.97	3.30						(MD--Nowakowski) GPWS USED ON FD 3 & 6
2147B	ARC	102194-002	DISSECTION POUCH ASSY, NEONATE,C.2	1	1.21	8.50	6.80	1.75	1657.6	1657.6	L2B	L2B	L2B	
NCDE			DISSECTION KIT C.2-NEONATE/OP2		0.55	21.59	17.27	4.45						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 6 & 15
2038A	ARC	A9SP-9501-M608-8	MAGIC CARPET	1	1.0	17.3	3.3	2.5	2338.8	2338.8	L9B	L9B	L9B	
100		2/5/98 REVISED-P/N, DWG TITLE NAME	MAGIC CARPET		0.45	43.94	8.38	6.35						(NP--McNaughton) GPWS USED ON FD 4 & 9
2038B	ARC	A9SP-9501-M608-9	MAGIC CARPET BASE	1	1.2	6.4	4.2	2.9	1277.4	1277.4	L9B	L9B	L9B	
100		2/5/98 REVISED-P/N, DWG TITLE NAME	MAGIC CARPET BASE		0.54	16.26	10.67	7.37						(NP--McNaughton) GPWS USED ON FD 4 & 9
2022	ARC	A9SP-9701-M200-6	ASSEMBLY, RODENT HOLDING BOX , ANIMAL ENCLOSURE MODULE	2	1.13	8.21	5.63	4.10	3105.5	6211.1	R8U	R8U	R8U	
GS			RAT HOLDING BOX		0.51	20.85	14.30	10.41						E100, E150, MD, NP USED ON FD 2, 4, 9, 14 E-100 SLEEPING POUCHES ARE INSIDE. 4 IN EACH BOX
2166	ARC	100902-007	TETHER, ESCHER	2	.30	4.0	2.0	1.0	131.1	262.2	L8B	L8B	L8B	
100			ESCHER TETHER ,		0.14	10.16	5.08	2.54						(NP--McNaughton) Used on FD 4 and 9 with E100 Data Computer
2180	ARC	A9SP-9501-M608-63	ESCHER WALL COVER	1	1.0	8.0	7.0	2.0	1835.4	1835.4	L9B	L9B	L9B	
100		2/7/98 DELETE-PART OF ESCHER KIT 1	ESCHER WALL COVER		0.45	20.32	17.78	5.08						(NP--McNaughton) GPWS
2168	ARC	A9SP-9501-M150-1	DATA COMPUTER ASSY (U8)	1	21.0	18.0	16.9	3.8	18942.8	18942.8	OH-13	OH-13	OH-13	EA (R+06 Hrs)
100			ESCHER DATA COMPUTER (SPARE)		9.53	45.72	42.93	9.65						(NP--McNaughton) SPARE. S/N 003 FOR FLIGHT
2169	ARC	A9SP-9501-M200-1	INTERFACE BOX ASSY (U7)	1	24.0	16.6	15.7	6.0	25624.8	25624.8	OH-13	OH-13	OH-13	
100			ESCHER INTERFACE BOX (SPARE)		10.89	42.16	39.88	15.24						(NP--McNaughton) SPARE S/N 003 FOR FLIGHT
2171	ARC	A9SP-9501-M608-13	ESCHER DATA COMPUTER-TO-INTERFACE BOX CABLE #1	1	0.6	5.0	5.0	2.0	819.4	819.4	L8B	L8B	L8B	
100			ESCHER DATA COMPUTER-TO-INTERFACE BOX CABLE 1		0.27	12.70	12.70	5.08						(NP--McNaughton)

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2170	ARC	A9SP-9501-M608-76	ESCHER INTERFACE BOX POWER CABLE	1	0.3	5.0	5.0	1.5	614.5	614.5	L8B	· L8B	L8B	
100		2598DELETE-PART OF ESCHERKIT6	ESCHER INTERFACE BOX POWER CABLE		0.14	12.70	12.70	3.81						(NP--McNaughton)
2179	ARC	A9SP-9501-M608-69	ESCHER LAPTOP NETWORK CABLE (SPARE)	2	0.7	5.0	5.0	2.5	1024.2	2048.4	L8B	L8B	L8B	
100		2798DELETE-PART OF ESCHERKIT4	ESCHER LAPTOP NETWORK CABLE (SPARE)		0.32	12.70	12.70	6.35						(NP--McNaughton) SPARE
2184A	ARC	102512-001	FIXATIVE KIT 1	1	.82	7.40	7.20	1.12	977.9	977.9	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
CDE			FIX KIT 1		0.37	18.80	18.29	2.84						(NP--Ross, Pompeano, Holstein, Fuller)GPWS USED ON FD 2
2184B	ARC	102218-001	FIXATIVE KIT 2	1	1.23	8.40	9.20	1.12	1418.4	1418.4	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
CDE			FIX KIT 2		0.56	21.34	23.37	2.84						(NP--Ross, Pompeano, Holstein, Fuller)GPWS USED ON FD 2 INCLUDES SPARES
2184C	ARC	102515-001	FIXATIVE KIT 12	1	1.33	9.60	9.20	1.12	1621.0	1621.0	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
CDE			FIX KIT 12		0.60	24.38	23.37	2.84						(NP--Ross, Pompeano, Holstein, Fuller)GPWS USED ON FD 14
2184D	ARC	102515-002	FIXATIVE KIT 13	1	1.33	9.60	9.20	1.12	1621.0	1621.0	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
CDE			FIX KIT 13		0.60	24.38	23.37	2.84						(NP--Ross, Pompeano, Holstein, Fuller)GPWS USED ON FD 14
2184E	ARC	102512-002	FIXATIVE KIT 14	1	.82	7.40	7.20	1.12	977.9	977.9	R9E	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
CDE			TFR FIX KIT 14		0.37	18.80	18.29	2.84						(NP--Ross, Pompeano, Holstein, Fuller)GPWS STOWED IN REF ON FD 12, USED ON FD 14 INCLUDES SPARES
2184F	ARC	102512-003	FIXATIVE KIT 15	1	.82	7.40	7.20	1.12	977.9	977.9	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
CDE			FIX KIT 15		0.37	18.80	18.29	2.84						(NP--Ross, Pompeano, Holstein, Fuller)GPWS USED ON FD 14 SPARES
2181	ARC	101772-002	MUFFLER ASSEMBLY, AEM	4	0.99	9.50	8.25	4.08	5240.1	20960.4	MF57O	N/A	MF57O	
GS			AEM MUFFLER		0.45	24.13	20.96	10.36						AEM
2182	ARC	102651-001	GAUNTLET KIT,ACCESS AND TRANSFER UNIT, AEM	1	.70	8.0	8.5	2.0	2228.6	2228.6	N/A	?	N/A	
GS		5297DELETE-STOWED IN ATU	AEM GAUNTLETS KIT		0.32	20.32	21.59	5.08						AEM, STOW IN ATU
2183A	ARC	102652-001	CLEAN-UP KIT, AEM	1	1.4	9.0	8.0	2.0	2359.7	2359.7	N/A	?	N/A	
GS		5297DELETE-STOWED IN ATU	AEM RAT CLEAN-UP KIT		0.64	22.86	20.32	5.08						AEM, STOW IN ATU
2032B	ARC	A9SP-9501-M608-17	ESCHER GROUNDING STRAP (SPARE)	1	0.1	4.0	2.0	2.0	262.2	262.2	L9B	L9B	L9B	
100			ESCHER GROUNDING STRAP (SPARE)		0.05	10.16	5.08	5.08						SPARE (NP--McNaughton) GPWS IS THERE A PIECE OF LSLE?
2110B	ARC	100902-006	OUTLET HOSE, IRU	1	1.056	10.0	12.0	1.40	2753.0	2753.0	L10B	L10B	L10B	TC (L-2 MONTHS)
GS			HOSE ASSEMBLY, IRU OUTLET		0.48	25.40	30.48	3.56						IRU, SPARE
2109B	ARC	100902-005	INLET HOSE, IRU	1 .	1.012	10.0	12.0	1.70	3343.0	3343.0	L10B	L10B	L10B	TC (L-2 MONTHS)
GS			HOSE ASSEMBLY, IRU INLET		0.46	25.40	30.48	4.32						IRU, SPARE
2186	ARC	A9SP-9501-M400-1	RODENT SLEEPING POUCH KIT	2	0.4	8.5	3.5	0.8	390.0	780.0	R8U	R8U	TRASH	
100		DELETE-PLACED IN RAT HOLDING BOX	ESCHER SLEEPING POUCH KIT		0.18	21.59	8.89	2.03						(NP--McNaughton) EACH KIT CONTAINS 4 POUCHES POUCHES ARE STOWED INSIDE RAT HOLDING BOXES, ONE KIT PER BOX
2006E	DLR	BTX-SPR-100	SPACER RINGS	2	0.18	4.17	4.17	0.71	202.3	404.6	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC3 SPACER RINGS		0.08	10.59	10.59	1.80						(NB--Horn) BOTEX
2009	DLR	BTX-CCK-100	GB CONTROL COVER KIT	1	0.15	1.0	4.5	7.0	516.2	516.2	L8U	BOTEX	BOTEX	
089			GB CONTROL COVER KIT		0.07	2.54	11.43	17.78						(NB--Horn) BOTEX GB Control Unit Used to prevent use of the wrong switches
2188	ARC	A7SP-8801-M2-3	ATR-4	1	NA	3.824	2.13	0.83	110.8	110.8	MF43H	MF43H	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			ATR-4		0.00	9.71	5.41	2.11						(NB--Horn) BOTEX
2189	ARC	102606-001	TRASH CONTAINMENT KIT	3	1.0	12.50	14.00	1.80	5161.9	15485.8	MF28K	MF28K	CENTER AISLE	EA (R+48 Hrs)
GS			TRASH KIT		0.45	31.75	35.56	4.57						USED ON FD 2,3,6,8,13,14,15 RETURN WITHIN WMS TRASH BAG. P/N V669-000668-027 (QTY 4) IN SPACELAB CENTER AISLE

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2190	ARC	102690-001	RAHF CAGE COVER KIT	1	.55	10.3	4.8	1.1	891.2	891.2	L10U	L10U	L10U	
NCDE			RAHF CAGE COVER KIT		0.25	26.16	12.19	2.79						GPWS, USED ON FD 6, 11,15
2191	ARC	102615-001	RADIATION CLEAN-UP KIT #1	1	NA	12.0	12.0	1.50	3539.6	3539.6	N/A	?	N/A	
093		5/29/7 DELETE-STOWED IN ATU	RADIATION CLEAN-UP KIT #1		0.00	30.48	30.4B	3.81						STOW IN ATU USED ON FD 3
2192	ARC	102615-002	RADIATION CLEAN-UP KIT #2	1	NA	12.0	12.0	1.50	3539.6	3539.6	N/A	?	N/A	
093		5/29/7 DELETE-STOWED IN ATU	RADIATION CLEAN-UP KIT #2		0.00	30.48	30.48	3.81						STOW IN ATU USED ON FD6
2194A	ARC	SED46114751-306	PERFUSION PUMP	4	2.5	9.25	5.00	2.37	1796.2	7184.9	L9U	L9U	L9U	EA (R+6 Hrs)
NCDE		4/27/98 REVISED-COMMENTS	PUMP		1.13	23.50	12.70	6.02						FD 8 & 15 (PRIMARY PUMPS) MUST BE STOWED WITH PERFUSION KITS SMART CARDS (2L324-2)
2195	ARC	102348-001	PERFUSION BAG WARMER ASSEMBLY	1	9.9	13.50	15.50	4.00	13716.0	13716.0	L3B	L3B	L3B	MVAK (L-10 Days)
NCDE			WARMING BAG ASSY		4.49	34.29	39.37	10.16						(MD--Riley, Kosik, Raymond)FD 8 & 15 Contains H 1A, H 2A, H.1B, H 2B and 3 syringe handle Kits
2196	ARC	102663-001	DEXTERITY VIDEO LIGHT	3	0.92	12.75	1.7	2.0	710.4	2131.1	L6B	L6B	L6B	
150			DEX / VID LIGHT		0.42	32.39	4.32	5.08						(MD--Walton) USED ON FD 6, 11, & 15
2197	ARC	102655-001	BASEPLATE, DISPATCHER	1	NA	11.0	7.75	0.1875	261.9	261.9	OH-12	OH-12	OH-12	
GS			BASEPLATE, DISPATCHER		0.00	27.94	19.69	0.48						GPWS USED ON FD 2 & 14 WITH ANIMAL DISPATCHER KIT
2005B	NASDA	T5-24202	VFEU WATER REFILL KIT ASSY	2	2.64	8.15	7.48	2.362	2359.6	4719.2	R9E	R9E	R9E	MVAK (L-60 Hrs)
088			WATER REFILL KIT (WATER)		1.20	20.70	19.00	6.00						(AQ--Highstein) VFEU 2 SEA & 2 FRESH WATER
2198	ARC	102700-001	ANIMAL HEALTH KIT	1	4.25	11.20	9.75	4.5	8052.6	8052.6	L2B	L2B	L2B	TC (L-2 MONTHS) EA (R+48 Hrs)
GS			VET KIT		1.93	28.45	24.77	11.43						CONTINGENCY
2199	ARC	102694-001	RESTRAINT STRAP KIT	1	0.5	12.0	5.0	1.25	1229.0	1229.0	OH-12	OH-12	OH-12	
GS			RESTRAINT STRAP KIT		0.23	30.48	12.70	3.18						STOW WITH RESTRAINT TABLE
2183B	ARC	102652-002	CLEAN-UP KIT, AEM	1	1.0	9.0	8.0	3.0	3539.6	3539.6	N/A	?	N/A	
GS		5/29/7 DELETE-STOWED IN ATU	AEM MOUSE CLEAN-UP KIT		0.45	22.86	20.32	7.62						AEM, STOW IN ATU
2201	ARC	A9SP-9203-M320-1	AEM TIE DOWN STRAP	3	0.49	6.0	1.0	3.0	295.0	884.9	N/A	?	N/A	
GS		5/29/7 DELETE-STOWED IN ATU	AEM STRAP		0.22	15.24	2.54	7.62						AEM, STOW IN ATU
2202	ARC	102722-001	RODENT GRIP PADS KIT	1	0.75	7.0	4.0	0.5	229.4	229.4	N/A	?	N/A	
GS		5/29/7 DELETE-STOWED IN ATU	RODENT GRIP PADS		0.34	17.78	10.16	1.27						USED IN RODENT HOLDING BOX STOW IN ATU.
2203	ARC	102312-001	TAIL MEASUREMENT KIT	1	.25	2.1	0.84	6.7	193.7	193.7	L2B	L2B	L2B	
NCDE			TAIL MEASUREMENT KIT		0.11	5.33	2.13	17.02						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 8, 13, 15 INCLUDES SPARES
2204A	ARC	102259-001	ANESTHESIA KIT L.1	1	.77	6.40	9.20	0.75	723.7	723.7	L3B	L3B	L3B	TC (L-2 MONTHS) EA (R+48 Hrs)
NCDE			NEONATE ANESTHESIA KIT L.1		0.35	16.26	23.37	1.91						(MD--Riley, Kosik, Raymond) GPWS CONTROLLED DRUG. INCLUDES SPARES USED ON FD 8
2204B	ARC	102259-002	ANESTHESIA KIT L.2	1	.77	6.40	9.20	0.75	723.7	723.7	L3B	L3B	L3B	TC (L-2 MONTHS) EA (R+48 Hrs)
NCDE			NEONATE ANESTHESIA KIT L.2		0.35	16.26	23.37	1.91						(MD--Riley, Kosik, Raymond) GPWS CONTROLLED DRUG INCLUDES SPARES USED ON FD 15.
2207A	ARC	A9SP-9501-M608-65	ESCHER HEADSTAGE #1	1	0.6	6.0	4.00	2.5	983.2	983.2	L8B	L8B	L8B	
100		2/5/98 DELETE-PART OF ESCHERKIT2	ESCHER HEADSTAGE #1		0.27	15.24	10.16	6.35						(NP--McNaughton) GPWS
2207B	ARC	A9SP-9501-M608-66	ESCHER HEADSTAGE #2	1	0.6	6.0	4.00	2.5	983.2	983.2	L8B	L8B	L8B	
100		2/5/98 DELETE-PART OF ESCHERKIT2	ESCHER HEADSTAGE #2		0.27	15.24	10.16	6.35						(NP--McNaughton) GPWS
2208	ARC	A9SP-9501-M608-62	ESCHER CAMERA CABLE	1	1.0	6.0	6.0	2.0	1179.9	1179.9	L9B	L9B	L9B	
100		2/7/98 DELETE-PART OF ESCHERKIT1	ESCHER CAMERA CABLE		0.45	15.24	15.24	5.08						(NP--McNaughton) GPWS

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NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2209	ARC	A9SP-9501-M608-10	ESCHER CAMERA #1	1	0.7	4.8	5.5	6.5	2812.0	2812.0	L8B	L8B	L8B	
100			ESCHER CAMERA #1		0.32	12.19	13.97	16.51						(NP--McNaughton) GPWS
2210	ARC	A9SP-9501-M608-11	ESCHER CAMERA #2	1	0.6	3.5	5.0	6.5	1864.0	1864.0	L8B	L8B	L8B	
100			ESCHER CAMERA #2		0.27	8.89	12.70	16.51						(NP--McNaughton) GPWS
2171	ARC	A9SP-9501-M608-67	ESCHER DATA COMPUTER-TO-INTERFACE BOX CABLE (SPARE)	1	0.6	5.0	5.0	2.0	819.4	819.4	L8B	L8B	L8B	
100		2793DELETE-PART OF ESCHERKIT3	ESCHER DATA COMPUTER-TO-INTERFACE BOX CABLE (SPARE)		0.27	12.70	12.70	5.08						(NP--McNaughton) SPARE
2031	ARC	A9SP-9501-M608-75	ESCHER INTERFACE BOX/GPWS DATA CABLE	1	5.4	12.0	8.0	3.5	5506.1	5506.1	L8B	L8B	L8B	
100		2593DELETE-PART OF ESCHERKIT6	ESCHER INTERFACE BOX/GPWS DATA CABLE		2.45	30.48	20.32	8.89						(NP--McNaughton)
2212	ARC	A9SP-9501-M608-14	ESCHER LAPTOP NETWORK CABLE	1	0.7	5.0	5.0	2.5	1024.2	1024.2	L8B	L8B	L8B	
100			ESCHER LAPTOP NETWORK CABLE		0.32	12.70	12.70	6.35						(NP--McNaughton)
2213	ARC	A9SP-9501-M608-15	ESCHER TRACKPAD	1	1.5	7.0	5.0	1.8	1032.4	1032.4	L9B	L9B	L9B	
100			ESCHER TRACKPAD		0.68	17.78	12.70	4.57						(NP--McNaughton)
2223	MMO	A9SP-9501-M160-1	LAPTOP COMPUTER/ADAPTER ASSY	1	7.5	10.3	11.7	2.5	4937.0	4937.0	L8B	L8B	L8B	
100			ESCHER LAPTOP		3.40	26.16	29.72	6.35						(NP--McNaughton) This configuration comes with Battery Pack (SED39126025-301. Hard Drive (SED39126024-301), Floppy Drive (SED39126023-301) and PCMCIA Card (EIA6805691) installed
2219	ARC	A9SP-9501-M608-18	ESCHER HEADPHONES	1	0.75	8.0	6.0	3.0	2359.7	2359.7	L9B	L9B	L9B	
100			ESCHER HEADPHONES		0.34	20.32	15.24	7.62						(NP--McNaughton)
2206	ARC	SDD46114759-701	BATTERY PACK, DRUG INFUSION PUMP	4	.6	1.0	1.0	7.84	128.5	513.9	L9U	L9U	L9U	
NCDE			PUMP BATTERY PACK		0.27	2.54	2.54	19.91						Spares for Perfusion Pumps
2214	ARC	A9SP-9501-M608-19	ESCHER LAPTOP ETHERNET ADAPTER	1	0.2	4.5	2.5	0.5	92.2	92.2	L8B	L8B	L8B	
100			ESCHER LAPTOP ETHERNET ADAPTER		0.09	11.43	6.35	1.27						(NP--McNaughton)
2215	ARC	A9SP-9501-M608-19	ESCHER LAPTOP ETHERNET ADAPTER	2	0.2	4.5	2.5	0.5	92.2	184.4	L8B	L8B	L8B	
100		2593DELETE-PART OF ESCHERKIT4	ESCHER LAPTOP ETHERNET ADAPTER		0.09	11.43	6.35	1.27						(NP--McNaughton) SPARE
2216A	ARC	EC2TC	PCMCIA ETHERNET CARD	1	0.1	3.5	2.5	0.5	71.7	71.7	L8B	L8B	L8B	
100		2593DELETE-INSIDE THINKPAD	ESCHER LAPTOP ETHERNET CARD		0.05	8.89	6.35	1.27						(NP--McNaughton) (INSTALLED INSIDE PGSC AT LAUNCH)
2216B	ARC	A9SP-9501-M608-71	ESCHER LAPTOP ETHERNET CARD (SPARE)	2	0.1	3.5	2.5	0.5	71.7	143.4	L8B	L8B	L8B	
100		2593DELETE-PART OF ESCHERKIT4	ESCHER LAPTOP ETHERNET CARD (SPARE)		0.05	8.89	6.35	1.27						(NP--McNaughton) SPARE
2218	ARC	522	BATTERY, 9V	1	0.2	2.0	0.5	0.5	8.2	8.2	L9B	L9B	L9B	
100			ESCHER BATTERY, 9V		0.09	5.08	1.27	1.27						(NP--McNaughton) SPARE
2217	ARC	E91	BATTERY, 1.5V	2	0.1	2.0	0.5	0.5	8.2	16.4	L9B	L9B	L9B	
100			ESCHER BATTERY, 1.5V		0.05	5.08	1.27	1.27						(NP--McNaughton) SPARE
2220	MMO	A9SP-9501-M608-72	ESCHER LAPTOP POWER CABLE (6 FT)	1	0.5	5.0	5.0	2.5	1024.2	1024.2	L9B	L9B	L9B	
100		2593DELETE-PART OF ESCHERKIT5	ESCHER LAPTOP POWER CABLE (6 FT)		0.23	12.70	12.70	6.35						(NP--McNaughton)
2221	MMO	A9SP-9501-M608-73	ESCHER LAPTOP POWER ADAPTER	1	1.5	7.5	3.3	2.5	1013.9	1013.9	L9B	L9B	L9B	
100		2593DELETE-PART OF ESCHERKIT5	ESCHER LAPTOP POWER ADAPTER		0.68	19.05	8.38	6.35						(NP--McNaughton)
2222	MMO	A9SP-9501-M608-23	ESCHER LAPTOP POWER CABLE (25 FT)	1	0.8	6.0	6.0	2.0	1179.9	1179.9	L9B	L9B	L9B	
100			ESCHER LAPTOP POWER CABLE (25 FT)		0.36	15.24	15.24	5.08						(NP--McNaughton)
2224	MMO	A9SP-9501-M608-24	ESCHER LAPTOP HARD DRIVE (SPARE)	1	0.5	6.0	4.5	0.7	309.7	309.7	L9B	L9B	L9B	
100			ESCHER LAPTOP HARD DRIVE (SPARE)		0.23	15.24	11.43	1.78						(NP--McNaughton) SPARE

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NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2127	MMO	10104-20019-01	WET WIPE DISPENSER	4	.25	4.5	2.63	2.13	413.1	1652.4	OH-12	OH-12	OH-12	
GS			WET WIPE DISPENSER		0.11	11.43	6.6B	5.41						STOW HORIZONALLY IF POSSIBLE
2205	ARC	102717-001	MAGNETIC STRIP ASSY	1	.10	12.75	1.0	.10	20.9	20.9	OH-12	OH-12	OH-12	
GS			MAGNETIC STRIP		0.05	32.39	2.54	0.25						STOW ON TOP OF RESTRAINT TABLE
2008A2	DLR	BTX-CR1b	CRIC1 CONTAINER	1	5.55	6.59	12.8	2.59	3580.1	3580.1	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC1b		2.52	16.74	32.51	6.58						(NB--Horn) BOTEX
2008C2	DLR	BTX-CR3b	CRIC3 CONTAINER	1	3.81	3.94	3.94	3.09	786.1	786.1	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC3b		1.73	10.01	10.01	7.85						(NB--Horn) BOTEX
2008C3	DLR	BTX-CR3c	CRIC3 CONTAINER	1	3.81	3.94	3.94	3.09	786.1	786.1	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC3c		1.73	10.01	10.01	7.85						(NB--Horn) BOTEX
2008C4	DLR	BTX-CR3d	CRIC3 CONTAINER	1	3.81	3.94	3.94	3.09	786.1	786.1	MF43H	BOTEX	MF43H	LL (L-18Hrs) EA (R+03 Hrs)
089			CRIC3d		1.73	10.01	10.01	7.85						(NB--Horn) BOTEX
2224	ARC	A9SP-9501-M608-1	ESCHER KIT 1	1	4.8	15.0	16.5	3.2	12978.6	12978.6	L9B	L9B	L9B	
100			ESCHER KIT 1		2.18	38.10	41.91	8.13						(NP--McNaughton)
2225	ARC	A9SP-9501-M608-2	ESCHER KIT 2	1	1.2	7.5	4.0	2.5	1229.0	1229.0	L8B	L8B	L8B	
100		ADD	ESCHER KIT 2		0.54	19.05	10.16	6.35						(NP--McNaughton)
2226	ARC	A9SP-9501-M608-3	ESCHER KIT 3	1	1.2	8.0	5.0	2.0	1311.0	1311.0	L8B	L8B	L8B	
100		ADD	ESCHER KIT 3		0.54	20.32	12.70	5.08						(NP--McNaughton)
2227	ARC	A9SP-9501-M608-4	ESCHER KIT 4	1	1.0	5.0	5.0	3.5	1433.9	1433.9	L8B	L8B	L8B	
100		ADD	ESCHER KIT 4 (SPARES)		0.45	12.70	12.70	8.89						(NP--McNaughton SPARE
2228	ARC	A9SP-9501-M608-5	ESCHER KIT 5	1	2.0	7.5	5.0	2.5	1536.3	1536.3	L9B	L9B	L9B	
100			ESCHER KIT 5		0.91	19.05	12.70	6.35						(NP--McNaughton
2229	ARC	A9SP-9501-M608-6	ESCHER KIT 6	1	6.3	13.0	11.0	3.5	8201.7	8201.7	L8B	L8B	L8B	
100		ADD	ESCHER KIT 6		2.86	33.02	27.94	8.89						(NP--McNaughton
2210A	ARC	102297-001	DETACHABLE HANDLES	1	0.6	1.56	5.25	6.84	918.0	918.0	L3B	L3B	L3B	
NCDE		ADD	SYRINGE PLUNGER KIT DIS 1 NEO		0.27	3.96	13.34	17.37						(MD--Riley, Kosik, Raymond) GPWS STOW WITH BAG WARMER USED FD8
2210B	ARC	102297-002	DETACHABLE HANDLES	1	0.45	1.44	4.05	6.75	645.1	645.1	L3B	L3B	L3B	
NCDE		ADD	SYRINGE PLUNGER KIT DIS 2 NEO		0.20	3.66	10.29	17.15						(MD--Riley, Kosik, Raymond) GPWS STOW WITH BAG WARMER USED FD15
2211	ARC	102349-001	CABLE ASSY, POWER, WARMER BAG	1	1.5	1.56	6.44	6.44	1060.2	1060.2	L3B	L3B	L3B	
NCDE		ADD	WARMING BAG CABLE		0.68	3.96	16.36	16.36						(MD--Riley, Kosik, Raymond) STOW WITH BAG WARMER USED FD8 & 15
2212	ARC	102729-001	COOLER, TISSUE	1	2.0	5.0	10.0	10.0	8193.5	8193.5	L2B	L9J	L2B	
GS		ADD	BAG, COOLER		0.91	12.70	25.40	25.40						GPWS USED ON POSSIBLY FD 2, 8, 14 AND 15
2213	ARC	TBD	SPRAY BOTTLE, RADIAC	3						0.0	N/A	?	N/A	
GS		5/29/7 DELETE-STOWED IN ATU	RADIAC SPRAY BOTTLE											AEM, STOW IN ATU, IN HOLDING BOXES
2214	ARC	V669-00070-009	WET WASH DISPENSER, HYGIENE	2	1.2	6.5	3.5	1.0	372.8	745.6	N/A	?	N/A	
GS		5/29/7 DELETE-STOWED IN ATU	WET WASHES		0.54	16.51	8.89	2.54						AEM, STOW IN ATU
	ARC	AD801-885D-M301-004	BAG, INTERLOCK SEAL	28	.03	10	10	.03	49.2	1376.5	R9M	R9M	R9M	
GS		ADD	CANISTER BAG		0.01	25.40	25.40	0.0B						STOW WITH DISSECTION CANISTERS, ONE BAG PER CANISTER HOLE

Neurolab ARC Stowage List

NL NO. / EXP	RESP	PART NUMBER	DRAWING TITLE / STOWAGE BOOK NAME	QTY	MASS EACH (lb/kg)	DIMENSIONS (in/cm) length	width	height	VOLUME EACH (cm^3)	VOLUME TOTAL (cm^3)	LOCATION launch	orbit	return	COMMENTS
2117	ARC	A9SP-9701-M210-1	STOWAGE CONFIGURATION, ACCESS AND TRANSFER UNIT (ATU)	1	9.92	19.36	14.86	9.63	45399.6	45399.6	MF57M	MF57M	MF57M	EA (R+48 Hrs)
GS		4/27/98 REVISED-COMMENTS	ACCESS AND TRANSPORT UNIT (ATU)		4.50	49.17	37.74	24.46						SUPPORTS AEM OPERATIONS INCLUDES GPTU (5184-101-B-01)
2063	ARC	100054-001	KIT, GEL PACK	1	10.6	12.0	12.0	3.0	7079.2	7079.2	AIRLOCK CEILING BAG	AIRLOCK CEILING BAG	AIRLOCK CEILING BAG	
GS		5/29/7 MMD ADD	GEL PACK KIT		4.81	30.48	30.48	7.62						CONTINGENCY
2149N	ARC	102370-003	FIXATIVE KIT 22	1	.72	7.40	7.20	1.12	977.9	977.9	L8J 4°C	L8J 4°C	L8J 4°C	MVAK (L-60 Hrs) EA (R+06 Hrs)
NCDE		3/2/8 ADD	TFR FIX KIT 22		0.33	18.80	18.29	2.84						(MD--Riley, Kosik, Raymond) GPWS USED ON FD 15, Second Shelf CR being prepared by ARC Science and MMO Stowage

9.0 Attachment 3: Neurolab Animal Experiments: A Preliminary Assessment

The following white paper documents preflight, inflight, and postflight events relevant to Neurolab animal experiments. It was prepared June 1998, shortly after the Neurolab Mission.

Neurolab Animal Experiments:

A Preliminary Assessment

prepared by

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Code SLO

June 1, 1998

Neurolab Animal Experiments: A Preliminary Assessment

The Neurolab mission included experiments which posed particular challenges in meeting animal husbandry requirements. Specifically, these were accommodation of 1) neonatal rodents, 2) marine fish, and 3) a collection of mixed freshwater species in a closed environmental system. Development of habitat hardware and procedures included extensive ground and simulated microgravity tests and limited spaceflight tests designed to ensure the health and welfare of these specimens under expected mission conditions. Thus, the mission was approached with a high degree of confidence. It is now appropriate to review the mission events and identify areas of study to improve our understanding of the results of these experiments. It is also worthwhile to note those habitats, equipment, and experiments which performed as expected and to assess the overall success of the mission.

I. Adult Neuronal Plasticity RAHF 7

Attachment 1: Water Utilization Data for RAHF 7 & ground controls

Twenty four adult male Fischer 344 rats were loaded into cages for MVAK integration into RAHF 7. Lixit count data obtained on the pad indicated that water utilization was less than preferred for some of the animals but after launch all animals exhibited normal utilization. On-orbit animal health was considered good as indicated by telemetered lixit data (Attachment 1) and food consumption which was comparable to previous ground tests. Science procedures consisting of light pulses and on-orbit dissections on Flight Day (FD) 2 and FD14 were performed according to the planned timeline and completed without anomalies. Animals recovered after landing were determined to be in excellent health by the KSC veterinarian.

Anomalies with RAHF hardware and Spacelab occurred on FD8. In RAHF 7 (adult rats), a failure of the bleed air fan was detected and then during the night, the Spacelab Recirculating Carbon Dioxide Removal System (RCRS) failed. Carbon dioxide levels in Spacelab reached just under 6 mmHg (~0.8%) which is well-below the 1.5% maximum limit established for the payload and would not have had a significant effect on the animals. Cross-ducting the air circulation system from RAHF 3 to RAHF 7 corrected the bleed air fan anomaly in RAHF 7 and the orbiter crew repaired the RCRS on the morning of FD9.

II. Adult Neuronal Plasticity AEM (2 units)

Four hyperdrive-implanted adult male Fischer 344 rats were loaded into 2 AEMs with divided cages for late access integration. Data had been collected from all rats prior to loading. On FD2, it was noted that three of the four hyperdrive dust caps had fallen off. Later that day, the crew reattached each dust cap with tape. The first planned behavior/recording session was performed as scheduled on FD4 for Rats #1, #2, and #3, however, timeline constraints prevented data collection from Rat #4 and a Replan Request for an additional session was submitted. The second planned session on FD9 was conducted again using only Rats #1, #2, and #3. The Replan Request remained active through the remainder of the mission, however, it was not implemented.

The health of all four rats was evaluated as excellent by the on-orbit veterinarian and they were energetic in the performance of their behavioral tasks. On FD14, during a routine health check, it was noted that the Hyperdrive assembly had become detached from Rat #4. The on-orbit veterinarian examined the animal and determined that tissue had overgrown the skull opening, that there was no sign of infection, and that the animal appeared in good health. Thus, it was not euthanized, but rather it was entered into the postflight R+1 day dissection flow to increase the N for the remainder of the Plasticity Team. It is worth

Final: 6/1//98

noting that both deselected animals and ground controls experienced loosening and/or loss of Hyperdrive assemblies.

III. Mammalian Development RAHF 3

Attachment 2: Water Utilization Data for RAHF 3, ground controls, ground test

Following preflight procedures developed by the Principal Investigators, 12 Sprague Dawley dams each with a litter of 8 neonates aged approximately Postnatal Day (PN) 7 were loaded into RAHF cages at Launch minus 40 hours. Integration of the cages into the RAHF was performed without anomaly and data streams indicated that the RAHF was operating as planned; lixit counts demonstrated that water utlization was similar to that observed during previous ground tests. This status was maintained over the next two days until STS-90 was launched on the second attempt. Telemetered data continued to demonstrate normal water utilization and RAHF operation after insertion. It is worth noting that during the prelaunch period, Spacelab carbon dioxide partial pressure gradually increased to 13 mmHg (1.7%) and then dropped precipitously to ~2 mmHg after activation. However, based on limited data available in the literature, it is unlikely that these conditions would have affected either the dams or the neonates.

On FD1, 2, and 6, the crew performed scheduled feeder tape and visual checks noting in their logbook that all animals appeared "OK." The first planned activity for the crew to perform with the Mammalian Development (MD) RAHF 3 animals was scheduled for Flight Day (FD) 6; E150 (Walton) Walking Behavior. However, delays in the timeline resulted in a shortened session and only the PN14 AEM animals were tested; no RAHF 3 cages were pulled at this time.

Cage 1 was pulled on FD8 to perform the scheduled perfusions/dissections (E143/Raymond) and no negative reports were received at the time. However, during the Crew Debrief (5/14/98), it was stated that two neonates from Cage 1 had died and only six were perfused/dissected; these deaths were subsequently confirmed to have occurred before the science operations were initiated.

The E150 activities scheduled for FD6 were rescheduled for FD8 to follow the perfusions/dissections. However, when Cage 11 was removed from the RAHF for the AWA procedures, only five animals of the eight were considered suitable for the procedures. All were reported to be dehydrated and it was found that none would perform the AWA tasks. The Payload Commander decided to terminate the experiment session at this point.

Subsequently, Cage 6 was pulled to comply with a FD7 Replan Request. This request had been based on an observed decreased lixit count from 50 to 22 during the previous two days and an assessment of the lixit function was planned to follow the E150 experiment. In Cage 6, five neonates were found dead with evidence of dam-induced trauma. A discussion between Rick Linnehan, the attending veterinarian, and Joe Bielitzki ensued and it was agreed that an evaluation of all cages was warranted. During the Replan Shift following FD8, it was learned that the crew had performed cage pulls and evaluations of animal conditions well into their Pre-Sleep Activity time. It was reported that all mortality appeared to have occurred over a fairly short time period.

This then was the first indication that there were problems with these animals with losses of up to 6 animals per cage in some cases. Specifically, 38 neonates were reported to be dead (5 had been euthanized), 19 were listed as "sick," and 39 were reported to be "healthy." Many of the neonates were provided with supplemental fluids with Baytril. The mortality

and morbidity seemed to be distributed among all but one cage, that is, all 8 neonates in Cage 10 were reported to be "healthy." Dead animals were stowed in Dissection Canisters.

On FD9, an approved Replan Request for the shortened FD6 E150 (Walton) Walking Behavior session was implemented and Cage 11 was taken to the General Purpose Workstation. At this time, the condition of the neonates was reported unsuitable to conduct the experiment although no details were provided. At the conclusion of FD9, the following was reported by the crew: one neonate was euthanized and was stowed with other dead animals, three were listed as "sick" and these were provided fluids with Baytril, but the majority of remaining animals including the dams were reported "healthy" and "doing well.". A total of 42 neonates were listed as "healthy" at this time.

No reports from the crew were received on FD10, and on FD11, E150 behavior operations were conducted on 8 neonates as planned. At the conclusion of FD11, a cage-by-cage status was received and crew comments indicated that continued attention was warranted. Rick Linnehan, the on-orbit attending veterinarian, speculated that maternal neglect was apparent. Gel-packs were added to all cages to mitigate the apparent dehydration and subcutaneous fluids were provided to some animals as well. Thirty six neonates were classified as "healthy" at this time including the entire litter in Cage 10.

The crew provided status at the end of the day on FD12, 13, and 15. Most animals were described to be "alert, responsive, active, and look good" although in a few instances some were labeled "urine-soaked, stunted, thin." It should be noted that the dam and litter of 8 in Cage 10 persisted to be listed as "healthy" with only one indication on FD11 that they were "mildly urine-soaked, tails healing, otherwise healthy." Leg muscle injections were performed as planned on 6 of 8 neonates from Cage 10 on FD13. After the FD15 scheduled perfusions of 6 neonates from Cage 10, the population labeled "healthy" was reduced to 31. Some continued to receive fluid supplements, and the crew moved neonates between cages to take advantage of those dams which seemed to be most actively caring for their young.

A comparison between the Neurolab flight and ground control groups and similar groups tested on the ground in the MD RAHF Housing Test (see Attachment 2) reveals a similarity in the water utilization data. Note that a decrease in RAHF 3 water utilization between FD7 and 8 correlates with the discovery of the neonate mortality. However, these are preliminary observations requiring more careful analysis and consideration.

The majority of on-orbit objectives for the investigator team were achieved based on tissues received and reports of behavioral sessions (video tapes not yet analyzed):
- FD8 perfusion of 6 of 8
- FD13 leg muscle injections and FD15 perfusion in 6 of 8
- FD6 behavior testing in 5 of 8
- FD11 behavior testing in 8 of 8.

According to the downlinked hardware performance data, RAHF 3 maintained the setpoint temperature of 26 ± 2° C at all times during the mission except during SPAF operations (e.g., cage transfer) when internal temperatures reflect that of the Spacelab cabin. Similarly, although RAHF does not actively control humidity, relative humidity was reported to be between 60 - 80% as expected.

RAHF 3 cages were turned over to Ames staff at Hangar L approximately 6:30 hours after landing. Unloading of the cages was performed in the Portable Clean Room with Dr. J. Bielitzki in attendance. The most notable finding was that the animals and cages were soaking wet and the neonates were hypothermic. Neonates were cleaned off and placed on

heating pads. The following table indicates the distribution of the 27 surviving neonates in RAHF 3 at cage unloading. The numbers reflect the efforts of the crew to maximize recovery by transferring some neonates to dams that were more adept at rearing neonates in microgravity.

RAHF 3 Cage Slot	Litter Designation	PI Assignment	DAM ID #	Neonates Surviving
01	P7-1	Raymond	3109	3
02	P7-2	Riley	3120	0
03	P7-3	Raymond	3114	5
04	P7-4	Baldwin Hypothyroid	3119	4
05	P7-5	Baldwin Euthyroid	3140	4
06	P7-6	Riley	3124	1
07	P7-7	Kosik	3135	0
08	P7-8	Shimizu	3131	0
09	P7-9	Kosik	3143	2
10	P7-10	Shimizu	3134	1
11	P7-11	Walton	3142	6
12	P7-12	Walton	3102	1
			Total	27

Considerable effort was exerted by the investigators to establish equitable and scientifically valid distribution of the recovered neonates and a significant proportion of primary objectives were achievable. Based on the data and tissues they received, they project the following return for their primary objectives: Baldwin - 75%, Kosik - 60%, Nowakowski - 100%, Raymond - 80%, Riley - 75%, Shimizu - 70%, Walton - 60%.

It should be recalled that preparations for accommodating neonates on Neurolab included the collaboration of two Neurolab Principal Investigators serving as consultants and a Mammalian Development Advisory Committee including NIH, IACUC, NASA, veterinary, and extramural scientist participation. Thus, with their participation, review, and advice, extensive tests on the ground with simulation RAHF cages as well as flight hardware established basic biocompatibility in the configuration used for the Neurolab mission. In addition, launch and landing simulations of g and acoustic profiles were conducted with no ill effects on dams or neonates. Moreover, a 9 day spaceflight test of cage volume was performed to establish basic feasibility for the Neurolab mission. For this test, since RAHF cages alone cannot provide life support without the associated environmental control systems, it was agreed by the Mammalian Development Advisory Committee to test a simulated RAHF cage volume inside an Animal Enclosure Module (AEM; NIH.R3, January, 1996).

Specifically, the youngest preferred age requested for Neurolab, PN5, as well as two older ages, PN8 and PN15, were included. The NIH.R3 test established a 95% survival in two litters of 10 neonates aged PN8 at launch. One of 20 flight neonates and one of 20 ground control animals died during the experiment. The PN8 flight animals weighed ~25% less than age-matched AEM ground controls and ~30% less than vivarium controls. Of two litters launched at PN5, only 6 survived and these weighed ~60% less than AEM and vivarium ground controls. Of the 2 litters aged PN15, 100% survived and were in good

condition on landing. These flight animals were equivalent to AEM ground controls, but both these groups weighed ~12% less than age-matched vivarium controls. Thus, while a distinct "cage effect" was documented, it was determined by the Advisory Committee that the results demonstrated the feasibility of supporting the Neurolab requirements with PN8 litters. For the purpose of the current discussion, it is important to note that while the total cage volume was simulated in the AEM Nursing Facility, the RAHF cage is rectangular so accommodation within the AEM volume required a 90° bend and an "L-shaped" cage. In addition, simulation of the RAHF cage floor was implemented, but other AEM cage surfaces were not modified and remained either stainless steel wire or foodbar plates due to design and flight constraints (e.g., payload weight, center-of-gravity).

Thus, one can speculate that, in microgravity, the rectangular RAHF cage configuration negatively influenced the ability of the dam to retrieve and nurse the neonates. It should be noted that a proposal to include a removable cage divider which would have halved the volume for the first half of the mission was discarded on the basis of the crew time required to remove the divider. In addition, early tests with hinged and spring operated "doors" through which the dam could pass while leaving the neonates in a "nest" area were rejected when injuries to neonates were observed as dams pulled them through the door. Rather, an "open door" divider with a 2" opening was employed to provide a limited restriction of the neonates to a nest area while enabling the dam to use the full extent of the cage. The Neurolab crew observed that although neonates would be left behind if the dam moved through the opening while nursing, they tended to be dispersed throughout the cage indicating that a stationary divider or active door indeed would have been preferable in the microgravity environment. In addition, the floor and top of the RAHF cages are open gridwork and wire mesh, respectively and provide a foothold for the animals, however, the two smooth side walls may have made purposeful locomotion more difficult. Finally, at present, it is difficult to explain the cause of the wetness of the animals although surely this would have contributed to their poor condition.

IV. Mammalian Development AEM (2 units)

In one cage-divided AEM, 18 timed-pregnant ICR-strain female mice were loaded 9 to a side prior to late access integration. After the launch delay, the AEM was returned to the Hangar and a contingency group of 18 timed-pregnant mice were loaded and integrated for the successful launch.

In the second cage-divided AEM, one Sprague Dawley dam with a litter of 7 PN13 neonates was loaded on each side prior to late access integration. These animals were not replaced after the launch delay and thus were 15 days old at launch.

Mouse injection/dissection operations were conducted as planned on FD3 and 6. Of the 18 females, 14 were pregnant; all were considered to be in excellent health and were extremely active. All mice were euthanized on-orbit as planned.

Behavioral testing on the Animal Walking Apparatus in the GPWS was conducted on 5 PN 13 neonates on FD6 (20 days old) and on 8 PN13 neonates on FD11 (25 days old). The operations were performed without anomalies and the animals were reported by the crew to be in excellent health. Upon recovery (31 days old), all PN 13 neonates were determined to be in excellent health by the KSC veterinarian.

V. Vestibular Function Environmental Unit (toadfish)

Attachment 3: on-orbit water quality analyses
Attachment 4: Necropsy Report
Attachment 5: NASDA Report on VFEU Water Quality

Four oyster toadfish, each with an electrode implanted in the vestibular nerve and a NASDA-provided head-mounted transmitter were loaded into the VFEU as follows:

Fish Package #1	Fish Package #2	Fish Package #3	Fish Package #4
Weight: 650 grams	Weight: 550 grams	Weight: 375 grams	Weight: 650 grams
Length: 30 cm	Length: 28 cm	Length: 26 cm	Length: 27 cm
Electrode:	Electrode:	Electrode:	Electrode:
wafer	Yoshida microwire	Highstein microwire	Highstein microwire
Implant date: 2/26/98	Surgery date:4/11/98	Surgery date: 4/6/98	Surgery date: 4/9/98

Preflight data collection indicated that prior to turnover and integration, all four fish were transmitting nerve impulse data as planned.

After Spacelab activation on FD1, downlinked data indicated anomalies for the air pumps serving Fish Packages (FP) 3 and 4 and they were placed into a staggered duty cycle (5 minutes ON / 10 minutes OFF). On FD2, the air pump for FP 3 failed and a ground test was configured to verify the ability of the fish to withstand 24 hours without active oxygenation; respiration rate was monitored during this test and it was considered successful. An Inflight Maintenance Procedure was developed and implemented on FD3 to route air from pump 4 into FP 3 and it was considered successful.

On FD5, data from air pump 2 indicated anomalous performance similar to air pump 3 prior to failure. On the same day, on the ground, one of the deselected fish was found dead with leakage of water through a failed electrode connector identified as the probable cause.

A repetition of the Inflight Maintenance Procedure was performed on FD7 to route air into FP 2 from air pump 1. Note that until this point and throughout the remainder of the flight, spontaneous nerve impulse data and that obtained during the crew-performed acceleration sessions continued to be interpreted by the Principal Investigator and NASDA to indicate that all four fish were alive and well.

Throughout the mission, water volume checks, water sample retrievals, and data tape changeouts were performed as planned.

On Recovery Day, the four FPs were received at 8:02 PM in the Space Station Processing Facility. The unload order and fish health are summarized in the following chart.

Unload Order	Microchip ID	FP ID	Health Status*	Unload time
1)	1510085C16	2	Excellent health. No sign of inflammation at pedestal or transmitter site	8:04pm
2)	1510087F52	3	Superficial necrosis at transmitter site	8:10pm
3)	1510083660	4	Dead, see Necropsy Report	8:21pm
4)	151008562C	1	Dead, see Necropsy Report	8:24pm

*All health observations were made by Dr. Allen Mensinger.

It was noted during the unload procedure that FP 3 and 2 fish experienced the on-orbit air pump anomalies on flight days 2 and 7, respectively. According to postflight water analysis of samples taken on FD3,6,9,12 and 15, NH4-N levels for FP 1 and 4 were at a level considered toxic (see Attachment 3). Note for comparison that water analysis in the SSPF Toadfish Holding Facility averaged as follows:

pH - 8.1 NH4-N (mg/L) - 0 NO2-N (mg/L) - 2-3 NO3-N (mg/L) - 20-100

Samples of the nitro-bacteria and carbon filter material were collected from each FP and sent for microbiological analysis; report is pending.

Necropsies were performed by the co-investigator, Al Mensinger, Ph.D., at the Florida Institue of Technology and the results are presented in Attachment 4. Briefly, based on the condition of the internal organs, Dr. Mensinger postulates that death occurred between approximately 24 - 72 hours prior to unloading (FD14 - 16) and he emphasized that the gills displayed the results of "adverse environmental conditions." However, in a recently received report (June 1, 1998), NASDA speculates that the fish in FP #4 died on or about FD10, that in FP #1 died after FD12, and that the observed water quality deterioration resulted from the decomposition of the fishes (see Attachment 5). Note that no mention is made in this report of the air pump failures in FP #2 and #3 and impacts to water quality that may have resulted. In addition, there are questions about the data interpretation in this report which are as yet unresolved. In any event, without additional tests with flight hardware, it will be difficult to determine which event occurred first, water quality degredation or fish death.

FP 2 and 3 fish were immediately placed in a transport cooler that contained pre-chilled and oxygenated water. A battery-powered air pump was placed in the cooler to provide a constant source of oxygen during transportation to the Florida Institute of Technology in Melbourne for postflight data collection.

VI. Closed Equilibrated Biological Aquatic System (swordtail fish, snails, plants)

Attachment 6: flight and ground hardware data

The following specimens were loaded into the CEBAS prior to late access integration:
- 4 adult swordtail fish
- 225 juvenile swordtail fish
- 38 adult snails
- 30 juvenile snails
- 50 grams hornweed.

Crew operations inflight were limited to daily video tape changeout and filter lint removal. No visual observations were possible or planned and no hardware performance data was available until after recovery.

Upon recovery, the following specimens were retrieved from the hardware:
- 4 adult swordtail fish
- 25 juvenile swordtail fish
- 27 adult snails
- 18 juvenile snails
- 189 hatchling snails
- 13 viable egg packs
- 119 grams hornweed.

The Principal Investigator (Wiederhold) will be able to meet all of his objectives with his specimens; some TBD impact was sustained by the DLR-sponsored co-investigators.

A review of the inflight hardware performance data (see Attachment 6) indicated that water temperature began to increase on FD9 and by FD14 exceeded 30° C with a spike at ~33° C on FD14. The plant lights were ON continuously beginning on FD10 except for two brief periods. Oxygen saturation dropped significantly on FD9 and continued to cycle to lower than acceptable levels for the remainder of the mission. The pH had begun to increase on FD5 and remained above 8.0 after FD9. It is worth noting that the "ambient" temperature, the measurement taken just inside the air filter inlet (CEBAS sensor data), rose on FD3 to 30-32° C and generally remained at this level until FD15.

VII. BOTEX (cricket eggs and larvae)

After the launch delay, the CRISP container, a passive middeck locker insert, was returned to Hangar L for specimen replacement and the following were loaded prior to late access integration for the successful launch:

- 750 cricket eggs
- 820 larval crickets.

On-orbit crew operations consisted of transferring the specimen containers to the BOTEX in Spacelab and activating the centrifuge, opening the BOTEX door daily to facilitate air exchange, and de-activating the experiment and transferring back to the middeck as late as possible in the mission prior to landing. All were performed without anomalies and the following specimens were recovered:

- 203 larvae from eggs
- 271 larvae.

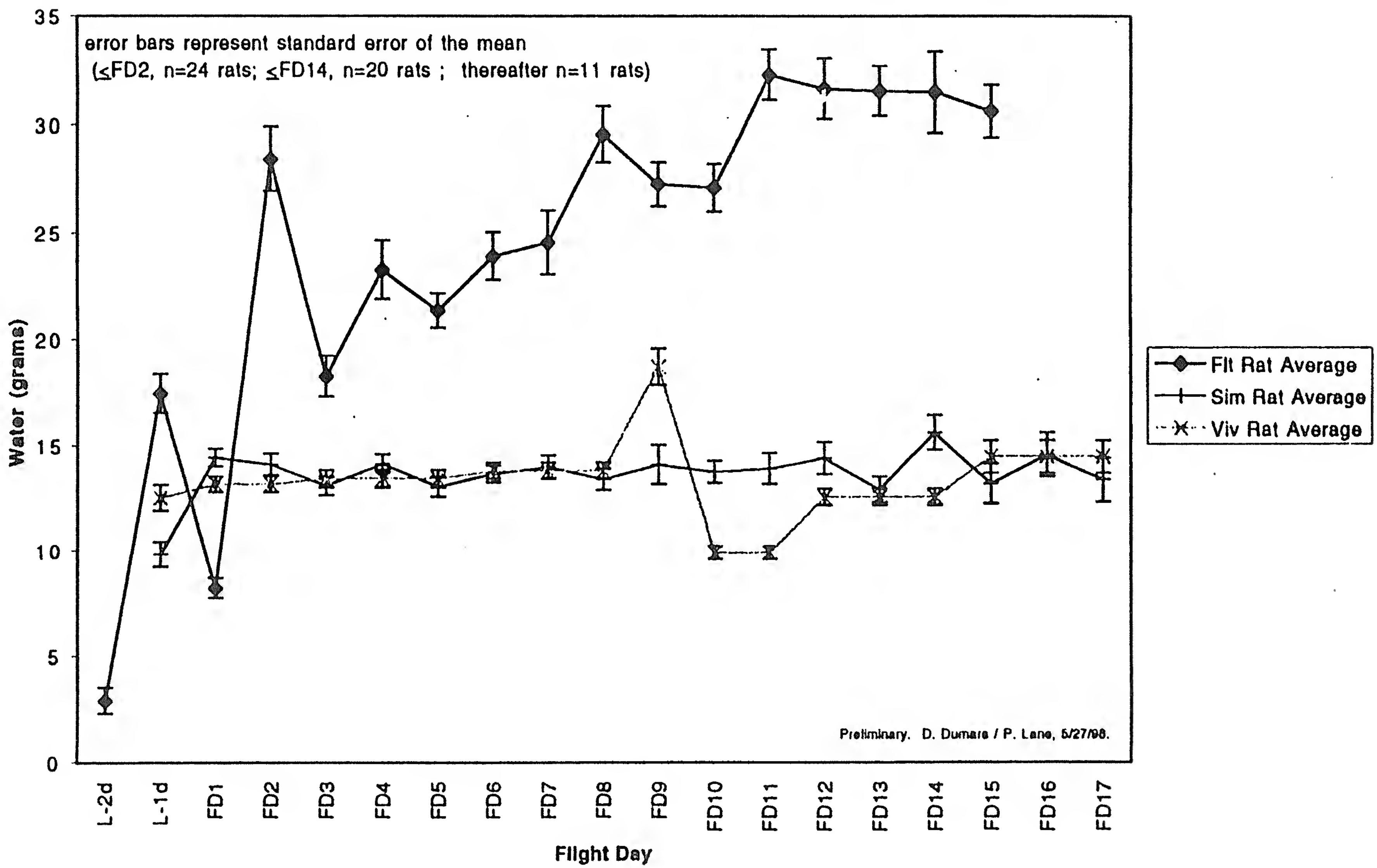
Overall survival for all specimens was 45% which compares to survival rates in ground tests of 20-30%. The Principal Investigator indicated that all of his objectives will be met with these specimens.

Conclusion

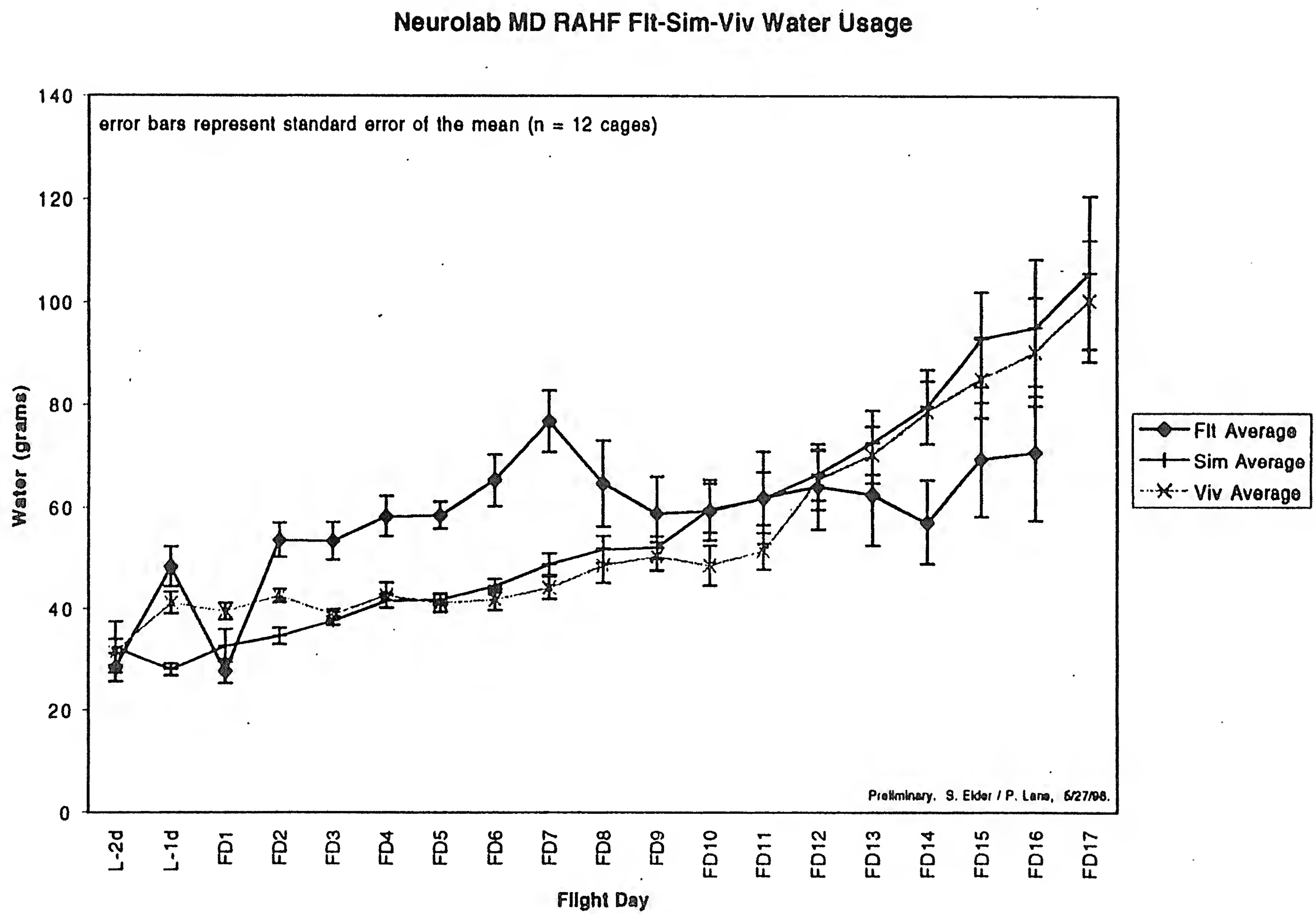
While the unexpected mortality in RAHF 3 and the VFEU impacted the anticipated science yield from these experiments, the mission as a whole produced sufficient data and specimens to meet the primary objectives of all of the investigators. Thorough reviews of hardware and operational performance are underway and insight into the observed problems will contribute to improved habitat design for future spaceflight experimentation.

ATTACHMENT 1

Neurolab NP RAHF Flt-Sim-Viv Water Usage



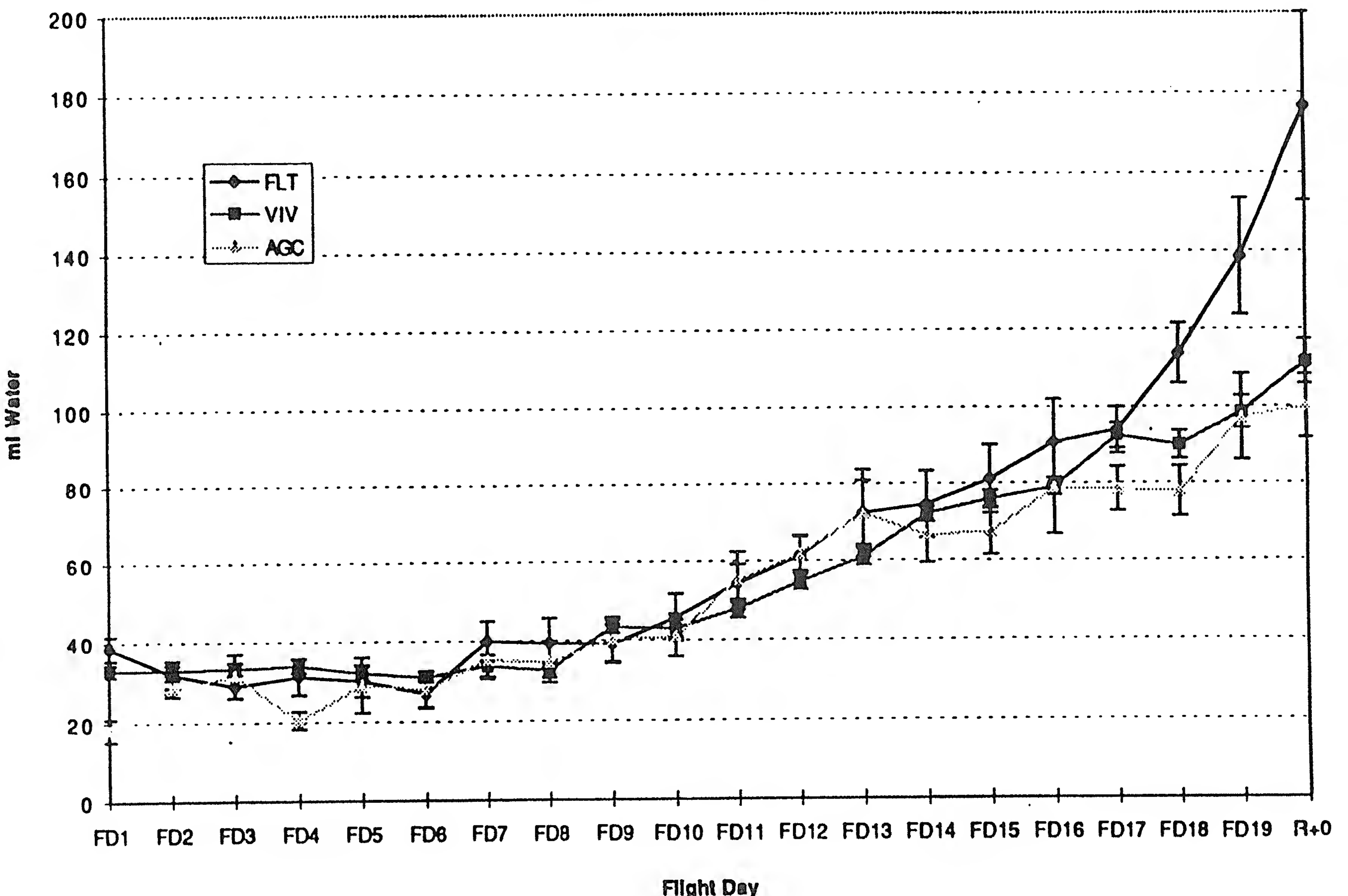
ATTACHMENT 2



Neurolab MD RAHF Flt-Sim-Viv Water Usage
error bars represent standard error of the mean (n = 12 cages)
Water (grams)
140
120
100
80
60
40
20
0
L-2d
L-1d
FD1
FD2
FD3
FD4
FD5
FD6
FD7
FD8
FD9
FD10
FD11
FD12
FD13
FD14
FD15
FD16
FD17
Flight Day
Preliminary. S. Elder / P. Lane, 5/27/98.
Flt Average
Sim Average
Viv Average

RAHF Test MD Water Consumption

(March - April, 1997)



T. Hughes
Sc. Datr team

ATTACHMENT 3

STS-90 VFEU FP WATER ANALYSIS RESULTS

FP1

	pH	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
Pre-Flight	8.1	< 0.1	< 0.1	5.6
FD3	7.8	< 0.1	< 0.1	26
FD6	7.9	0.5	< 0.1	37
FD9	7.7	0.3	< 0.1	41
FD12	7.7	0.9	< 0.1	46
FD15	7.8	14.0	0.2	53
Post-Flight	8.0	51.4	1.2	58

FP2

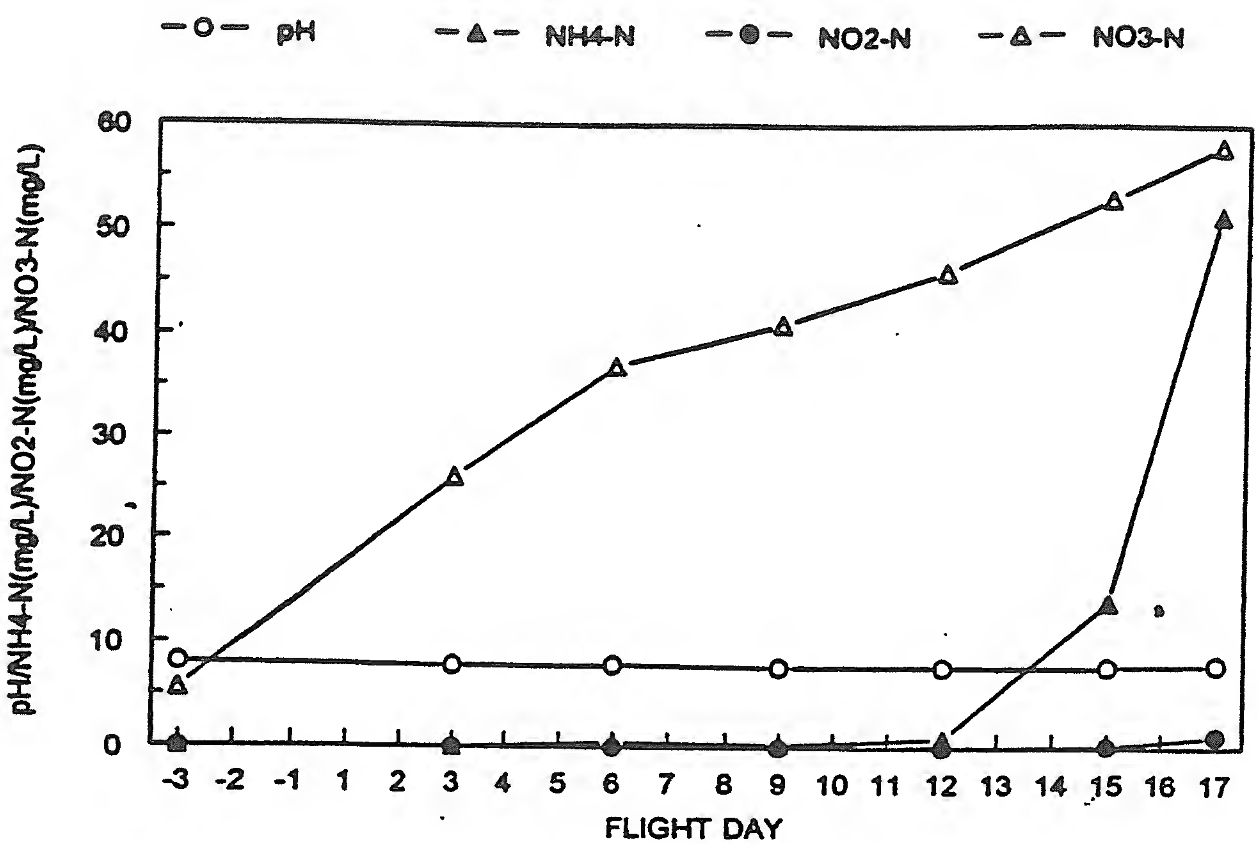
	pH	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
Pre-Flight	8.1	< 0.1	< 0.1	4.8
FD3	7.8	< 0.1	< 0.1	10
FD6	7.9	< 0.1	< 0.1	12
FD9	7.8	1.5	< 0.1	14
FD12	7.8	0.2	< 0.1	16
FD15	7.8	1.1	< 0.1	23
Post-Flight	7.7	7.8	< 0.1	27

FP3

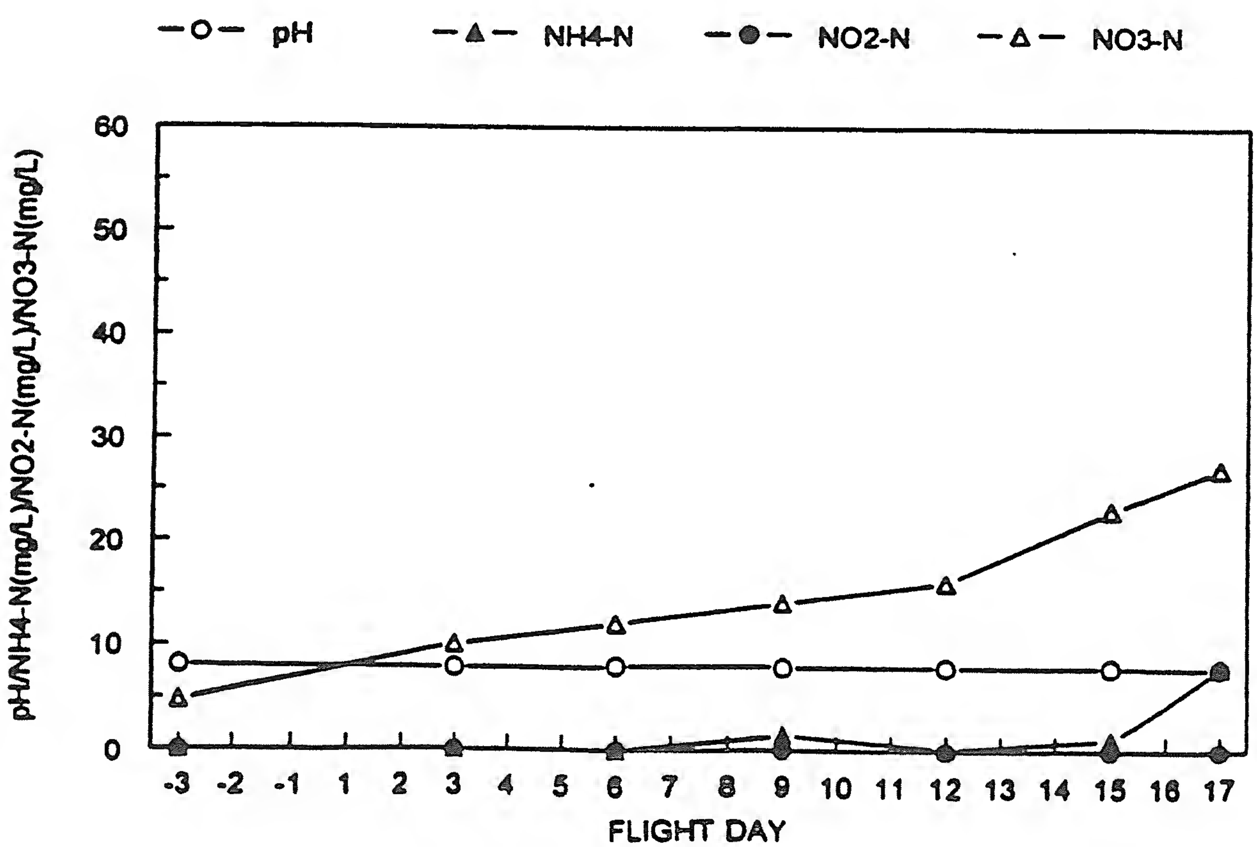
	pH	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
Pre-Flight	8.1	< 0.1	< 0.1	4.2
FD3	7.9	< 0.1	< 0.1	12
FD6	7.9	1.2	< 0.1	16
FD9	7.9	0.2	< 0.1	18
FD12	7.9	0.6	< 0.1	21
FD15	7.8	0.8	< 0.1	24
Post-Flight	7.7	2.8	< 0.1	26

FP4

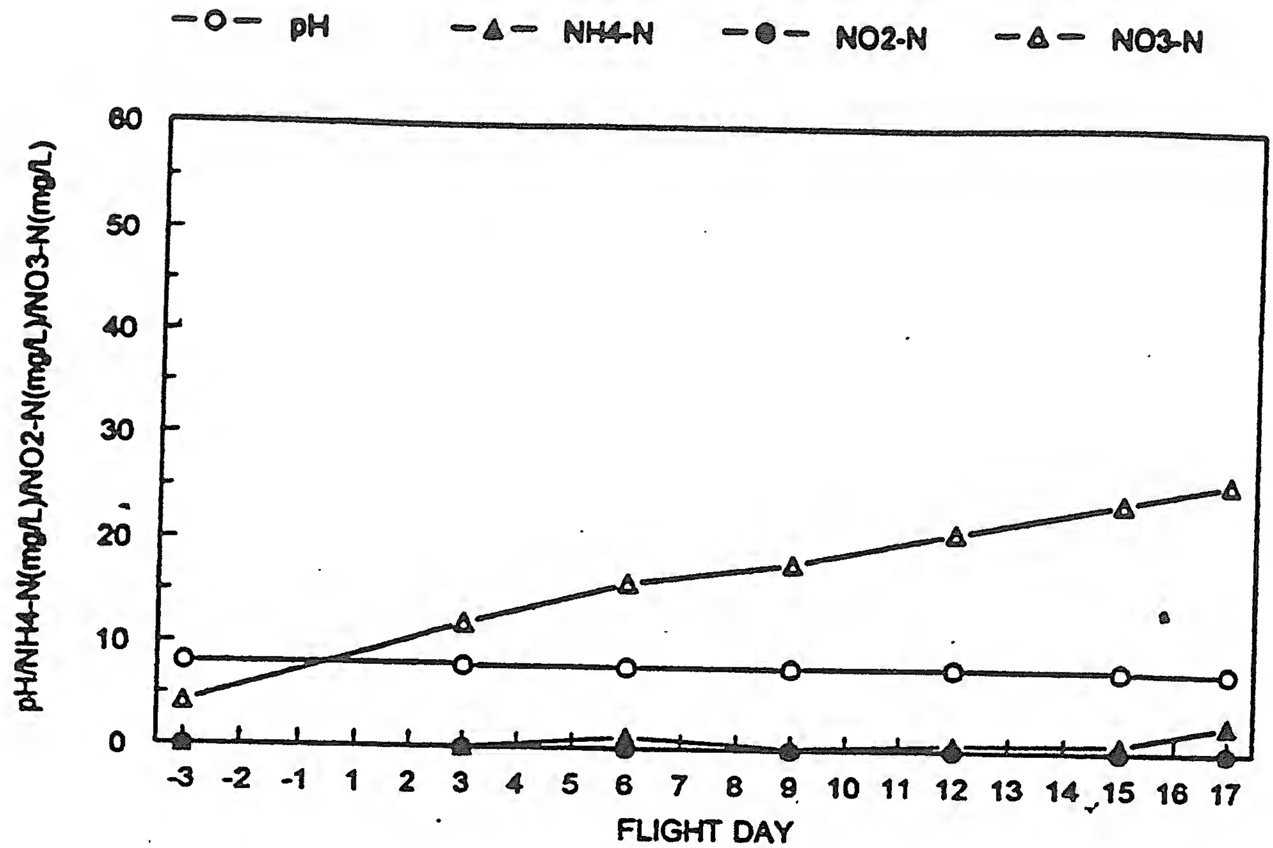
	pH	NH_4-N (mg/L)	NO_2-N (mg/L)	NO_3-N (mg/L)
Pre-Flight	8.2	< 0.1	< 0.1	4.2
FD3	7.9	< 0.1	< 0.1	9.6
FD6	7.9	< 0.1	< 0.1	11
FD9	7.9	0.9	< 0.1	16
FD12	7.9	8.7	0.1	22
FD15	7.9	38.6	< 0.1	26
Post-Flight	7.8	61.7	0.3	27



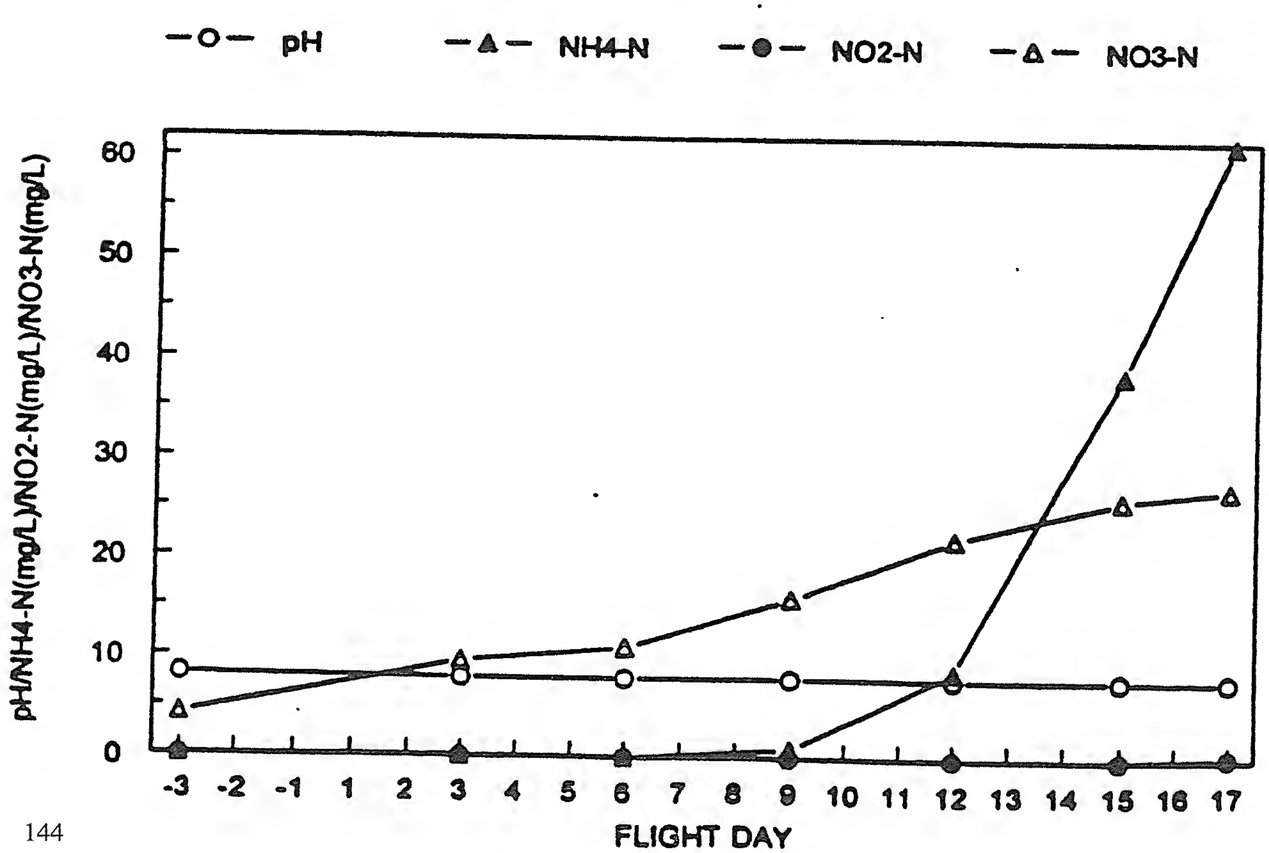
FP2 WATER ANALYSIS RESULTS



FP3 WATER ANALYSIS RESULTS



FP4 WATER ANALYSIS RESULTS



ATTACHMENT 4

E088 Necropsy Report
Prepared by Al Mensinger, Ph.D.
received at ARC May 27, 1998

Externalexamination

F1 and F4 did not show any external signs of infection or parasites. Both were encased in a heavy mucous coat. Gill arches and filaments were frayed and reduced which is indicative of adverse environmental conditions

Internalexamination

F1 was a male. Internal organs and mesenteries had a moderate concentration of encysted nematodes, however this is not abnormal and should not have affected the physiology of the animal. Internal organs were all normal and did not exhibit any sign of decay. Liver was slightly reduced for animal of this size but within normal.

F2 was a very gravid female with over 50% of the eggs full size. No internal signs of parasites. Internal organs were all normal and did not exhibit any sign of decay. Blood remained fluid in most vessels

Conclusions

Initial macroscopic examination had placed time of death, 3-5 days prior to examination based on the mucous coat. However, this estimation contrasts with the state of external organs. Past necropsies of fish that have been dead for 48-72 hrs usually manifest advanced signs of internal decay and the hatching of the encysted nematodes. The heavy slime coat may have been a manifestation of the small water volume.

In summary, both F1 and F4 showed external (gills) signs of adverse environmental conditions. Based on the condition of the external organs, time of death was probably 24-72 prior to examination.

ATTACHMENT 5

NATIONAL SPACE DEVELOPMENT AGENCY OF JAPAN
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(81-298-52-2773, Fax: 81-298-50-2233)

May 29, 1998

Dr. Louis Ostrach
Project Scientist
NASA Ames Research Center
Moffet Field, CA, USA

Dear Dr. Ostrach

I am submitting a report on the VFEU water and the capability analysis regarding the biological filter system for fish life support during the Neurolab Mission. The water samples were basically taken during the flight by crew and also pre- and post -flight in the KSC facility. As written in this report in details, the bioreactor as a part of the VFEU life spport system found to be normally functioned during the mission period based on our analysis. It may be very difficult to find out real reason of fish death from this analysis alone.

If you have any question or need further suppot data, please address your concerns directly to me.

Shunji Nagaoka

Shunji Nagaoka, Ph.D.
Space Utilization Research Center
National Space Development Agency of Japan

cc :Ken Souza, Chris Maese/ARC
J. Vernikos, Mary-Anne Frey/Hqs
S. Highstein, K, Yoshida
H. Takamatsu, S. Matsubara

Report on water quality in VFEU life support system during the Neurolab flight

Shunji Nagaoka, PhD. , Project Scientist, NASDA Neurolab Project
Space Experiment Department, NASDA

Purpose

This document describes results of VFEU life support capability analysis based on water quality measured by pH, ammonium, nitrite and nitrate ions concentrations in the sampling water of VFEU Fish Packages during the Neurolab mission period as well as in pre- and post flight phase.

Method

After stabilizing the bacterial filter system in four VFEU Fish Packages, the nitrifying activities of the filters are measured and evaluated at KSC laboratory by the water sampling before the late access of the hardware. The water sampling operations were timelined and performed five times (MD3, 6, 9, 12, 15) by crew during the Neurolab flight. The on-orbit sampling water was analyzed after retrieval of the flight water together with post-flight samples, which was directly taken from the VFEU Fish Packages as soon as the hardware was returned to KSC laboratory.

The water analysis was made by measuring pH, ammonium, nitrite and nitrate ions concentrations. The bacterial activities of the filter system was evaluated by loading low concentration of ammonium ion into the recycled water and subsequent time dependent analysis of the ionic concentrations for 8 hours.

Results

Initial bacterial filter capability

The bacterial filter system was prepared and well stabilized at KSC laboratory prior to the fish loading. The final nitrifying activity of four Fish Packages were all same and showed very high activity as shown in the Fig.-5, 0.65g N/Ld, which indicated a 0.65 g of nitrogen oxidation capability per one litter of the filter matrix in a day. The high activity was achieved by the preparatory culture with high dose of ammonia loading.

Water Quality in Fish Packages #2 and #3

As shown in the Fig.-4, the nitrate concentrations in the Fish Packages increased approximately linear fashion with time. Assuming the nitrate accumulation is linear, we can estimate the ammonia production from the fishes in Fish Package #2 (FP2) and Package #3 (FP3) during the flight period, because almost no intermediate nitrogen product remained in the water. The calculated ammonia production rates for FP2 and Fp3 are very low, less than 0.1 g-N/Ld. The estimated rates over the mission period are 0.023g-N/Ld for FP2 and 0.012g-N/Ld for FP3, indicating very low metabolic rate of the fishes during the flight period. This results are also consistent with the low nitrifying activities of the filter system measured immediately after the mission, 0.1-0.2 g-N/Ld for both FP2 and FP3 as shown in the Fig.-5. It is because the bacterial reactor system is known to show quick adaptation in the nitrifying activity within a few days depending on the environmental ammonia loading rate. Such responses were clearly observed during the sequentioal multiple assay of the filter system after the flight . In the Fig.-5, the nitrifying activities increased rapidly in the multiple addition of exess ammonium salt.

The ammonium concentration remaining in the water during the flight was approximately 1 ppm or less. The nitrite concentration was perfectly controled in both FP2 and FP3 in all phase of the mission, indicating below the detection level. From all the data, we could concluded that the biological filter system in FP2 and FP3 functioned normally and had enough capability for the fish life support in the experiment period.

Water Quality in Fish Packages #1 and #4

As shown in Fig.-2, the ammonium concentration rapidly increased after MD12 in Fish Package #1(FP1) and MD9 in Fish Package #4 (FP4). The ammonium concentration in the FP1 at MD 15 was 14.0 ppm while the FP4 showed further higher value, 38.6 ppm at same day. Those abnormal levels of ammonium accumulation clearly indicated the death of the fishes and a subsequent decomposition.

Based on the ammonium accumulation profiles, we can estimate when the fishes died during the mission. In the FP1, the ammonium concentration only increased significantly at MD 15, while in the FP4, the concentration was

already significant at MD 12. We therefore could estimate with rather high accuracy that one fish in the FP1 died after MD 12, may be around MD 13, and another fish around MD 10. The fish body usually starts decomposition rather rapidly and produce ammonia within one day even 13 deg. C based on our laboratory experiences. Before the fishes died, no anomaly in the water quality in both Fish Packages was observed. The small increase in the nitrite concentration in the water at later phase was understood as a reactivation of resting nitrifying bacteria due to the sudden increase of ammonia. This behavior was typically observed during the initial phase of the bacterial filter activation.

The nitrite concentrations in both Fish Packages was quite low during the flight period, but tend to increase at the end of the mission in case of FP1. The post-flight water analysis, the nitrite concentrations were 1.2 ppm in FP1 and 0.3 ppm in FP2, also showed a slightly higher than in-flight. This result may be due a temporary accumulation of nitrite during the reactivation of the bacteria system induced by rapid accumulation of ammonia generated by the fish decomposition.

We therefore reasonably concluded that the rapid increase of ammonium concentration was not a primary factor to kill the fishes, but was a result of the fish body decomposition. It may be very difficult to investigate what really caused the fish death only from the water analysis data.

Other parameters

The pH values in all Fish Packages water were plotted in Fig.-1, but showed no significant change, ranged from pH 8.1 to pH 7.8 in entire mission period.

The nitrate accumulation rate in the FP1 was significantly higher than other three Fish Packages. This indicated that fish metabolism in FP1 was significantly higher than other three. The reason of the difference is however not clear. It may be due to the difference in fish size loaded in FP1, which seems to be the largerest in the flight specimens, or other physiological differences relating metabolism such as sex or an infection.

Conclusion

In all Fish Packages, the nitrite concentration was mostly below the detectable level through the entire mission period, except in the MD15 sample

of FP1, 0.2 ppm. The ammonium concentration was also well controlled mostly under 1ppm while the fishes alived as expected. A small deviation was observed in the ammonium concentration in the middle of the mission days, when the water temperature was fluctuated between 13 to 15 deg. C, but returned to normal before the next sampling. It may be due to the effect that the rapid temperature change often disturb the balance of the bacterial reaction.

Based on the water analysis, we could concluded that all biological filter systems in VFEU functioned normally adapting their nitrifying capability to the individual environment of ammonium production, and could maintained the water quality under an adequate level as required for the fish life support during the mission. Although two fishes died in the later phase of the flight, the analysis of the water samples taken 3 days interval allowed to estimate the approximate time of the fish death. The reason of the fish death, however, could not be clearly understood from this analysis .

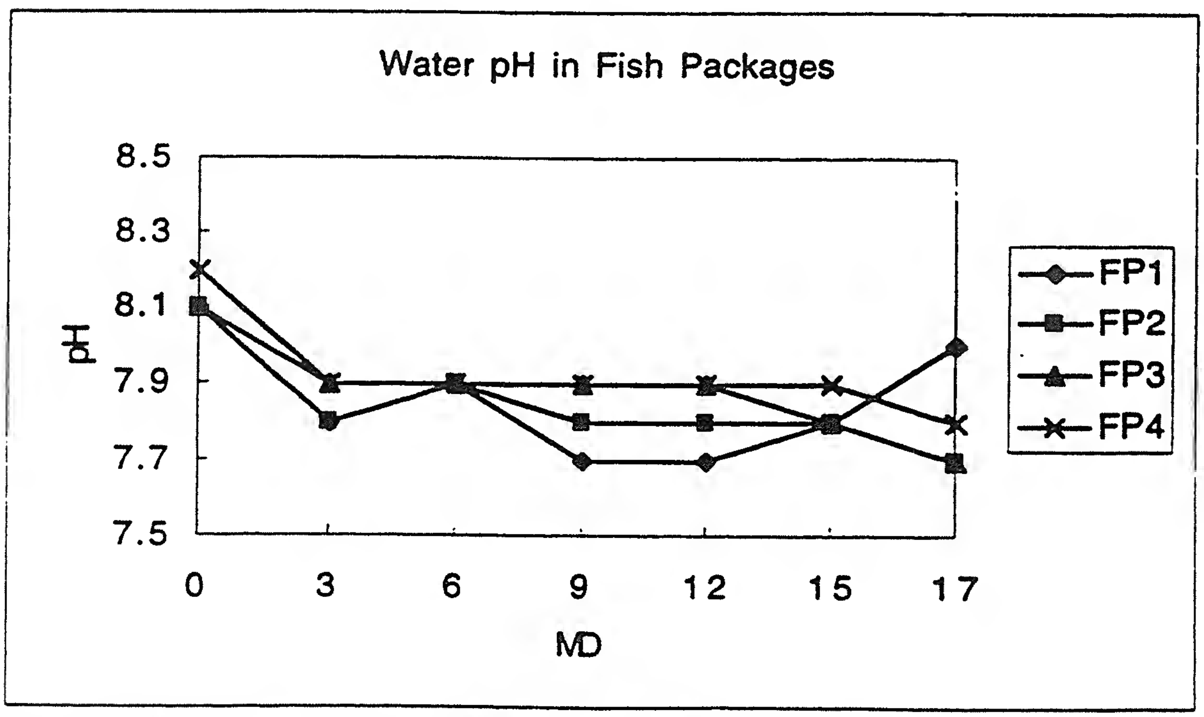


Fig.-1 Water pH trend in Fish Packages during Neurolab mission
MD 0: pre-flight sampling, MD 17: post-flight sampling

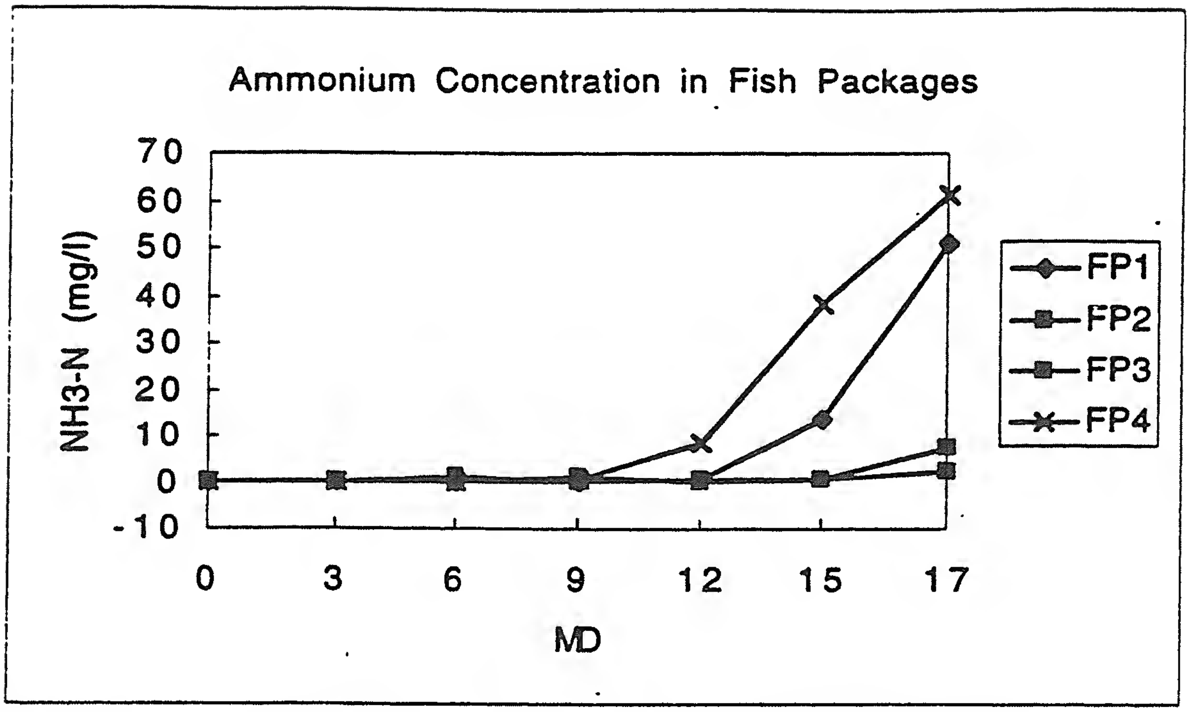


Fig.-2 Ammonium Concentrations in Fish Packages during Neurolab mission
MD 0: pre-flight sampling, MD 17: post-flight sampling

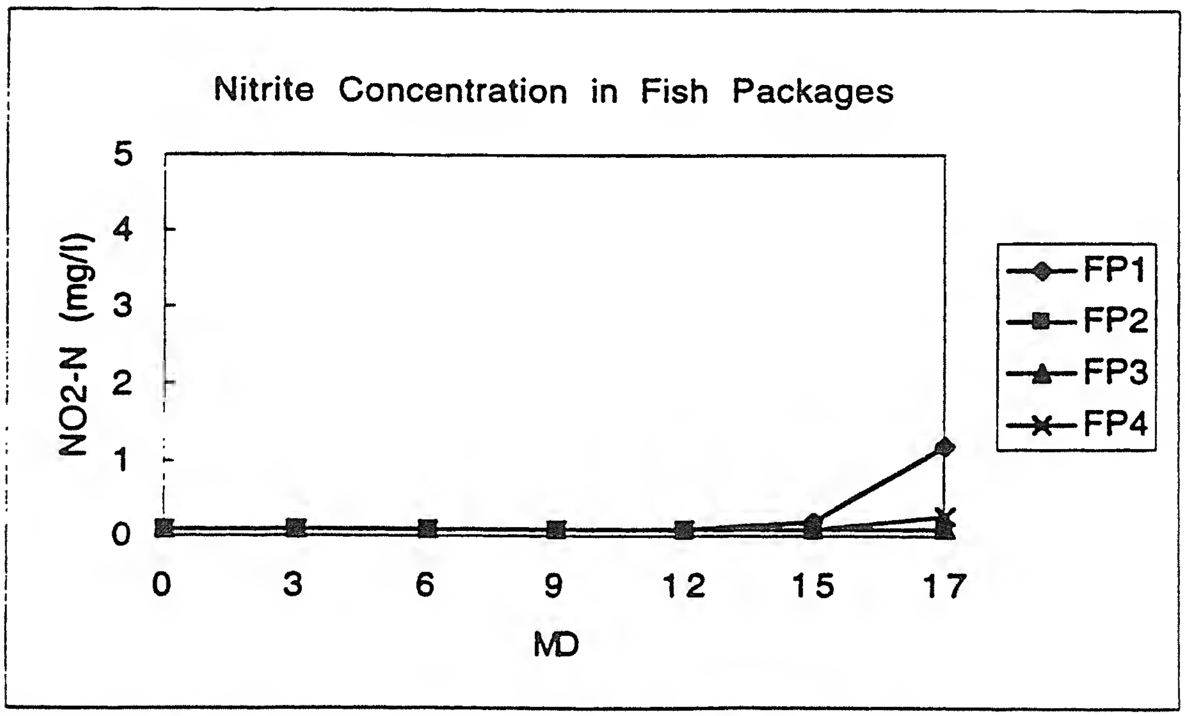


Fig.-3 Nitrite concentrations in Fish Packages during Neurolab f mission
MD 0: pre-flight sampling, MD 17: post-flight sampling

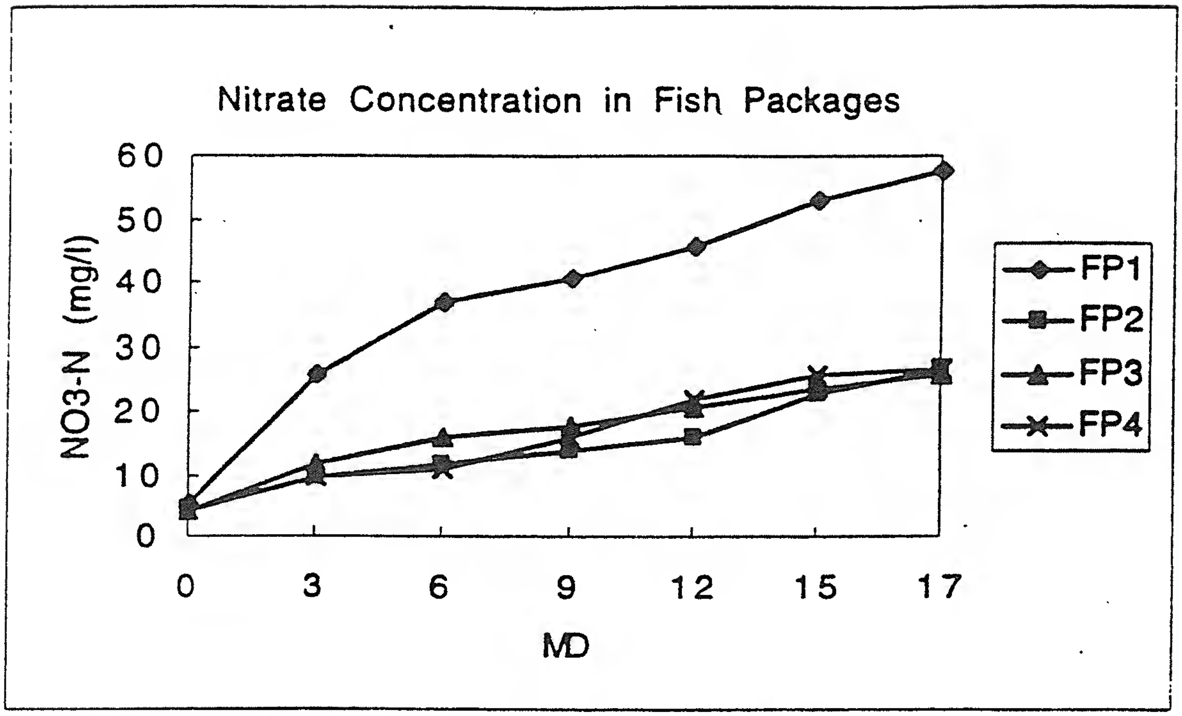


Fig.-4 Nitrate concentrations in Fish Packages during Neurolab mission
MD 0: pre-flight sampling, MD 17: post-flight sampling

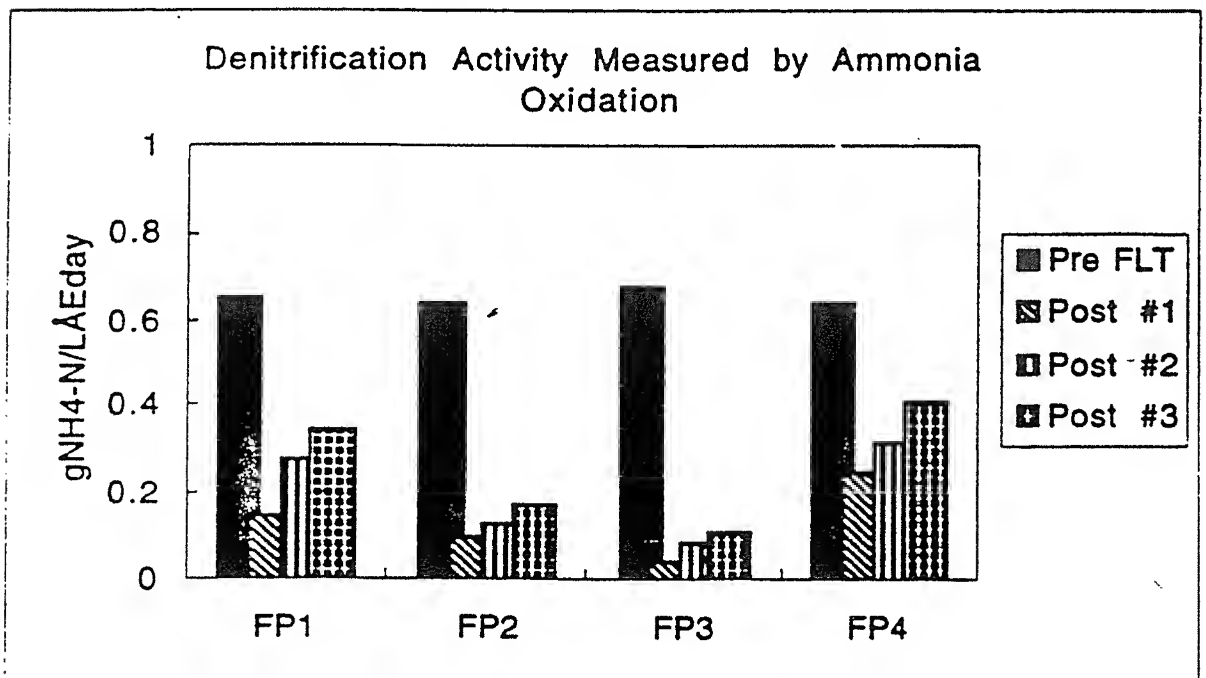


Fig.-5 Nitrifying activities of bacterial filters in Fish Packages in pre- and post-flight of Neurolab mission. The post- flight activity measurements were performed three times as shown in the figure (Post#1, Post#2 and Post#3) sequentially with two different temperatures (13 C and 14 C).

ATTACHMENT 6

C.E.B.A.S. - Mini Module Experiment
Worksheet

Experiment-Name	N-M-I

Date			
L-12	L-5	L	L+16
04.04.98	11.04.98	17.04.98	03.05.98

B. glabrata		
	L-5	L+16
Number of Adults	38	27
Survival Rate (%)	-	71,1
Weight of Adults (g)		11,6
Number of Neonates	30	207
Number of Spawn. Packs	-	12
Spawn. Packs on Video	-	12

Water Parameter		
	L-2	L+16
NO_3^- (mg/l)	18	35
NO_2^- (mg/l)	0,062	0,027
NH_4^+ (mg/l)	0,029	0,166
P (mg/l)	0,102	0,459
Cl^- (mg/l)	4,27	0,98
Ca^{++} (mg/l)	30	200
pH	7,2	8,8
Conductancy (µS)	276	952
Alkalinity	1,84	0,53
Acidity	0,45	0
Total Hardness	10	38,5
Carbon Hardness	7	2

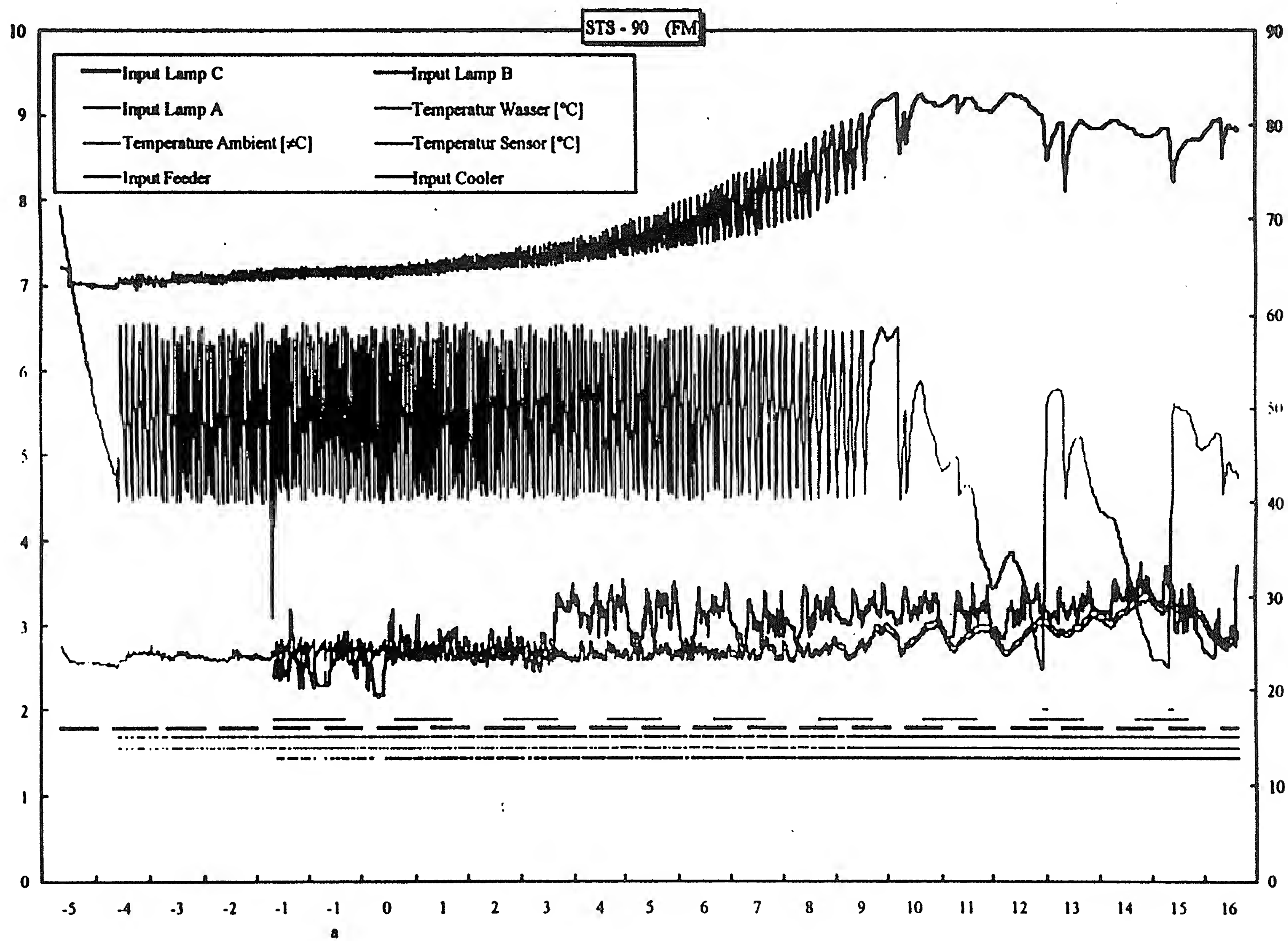
C. demersum		
	L-5	L+16
Weight (g)	49,97	119,1
Biomass Incr. (%)		238,3
Algae (g)	nd	nd

X. helleri (adult)				
	L-7		L+16	
	(g)	Days after Parturition	(g)	Days after Parturition

Female #1	2,02	L-18 to L-8	1,96	order of females
Female #2	1,71	L-18 to L-8	1,41	after retrieval
Female #3	1,72	L-18 to L-8	1,78	according weight
Female #4	1,56	L-18 to L-8	1,31	-
Total Weight	7,01		6,46	-
Avg. Weight	1,75		1,61	-
StDev.	0,19		0,31	-

X. helleri (juvenile)		
Born L- 9 to L-7		
	L-3	L+16
Avg. Number (Neo-Tank)	200	23
Survival Rate (%)		11,5
Avg. Weight (mg)	13,74	14,96
StDev (mg)	2,19	2,52
Avg. Number (Filter)	25	2
Survival Rate (%)		8
Avg. Weight (mg)	13,74	
StDev (mg)	2,19	

Aliens	Number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Input Lamp C
Input Lamp B
Input Lamp A
Temperatur Wasser [°C]
Temperature Ambient [≠C]
Temperatur Sensor [°C]
Input Feeder
Input Cooler
a

C.E.B.A.S. - Mini Module Experiment Worksheet

Experiment-Name	N-M-2

Date			
L-14	L-5	L	L+16
09.04.98	16.04.98	22.04.98	08.05.98

Water Parameter		
	L-2	L+16
NO_3^- (mg/l)	18	38
NO_2^- (mg/l)	0,050	0,181
NH_4^+ (mg/l)	0,043	0,176
P (mg/l)	0,154	0,331
Cl^- (mg/l)	4,51	1,62
Ca^{++} (mg/l)	130	222,92
pH	7,2	8,4
Conductancy (µS)	286	987
Alkalinity	2,07	0,81
Acidity	0,55	0
Total Hardness	10	25
Carbon Hardness	6,1	3

B. glabrata		
	L-5	L+16
Number of Adults	38	28
Survival Rate (%)	-	73,7
Weight of Adults (g)		12,8
Number of Neonates	30	155
Number of Spawn. Packs	-	13
Spawn. Packs on Video	-	11

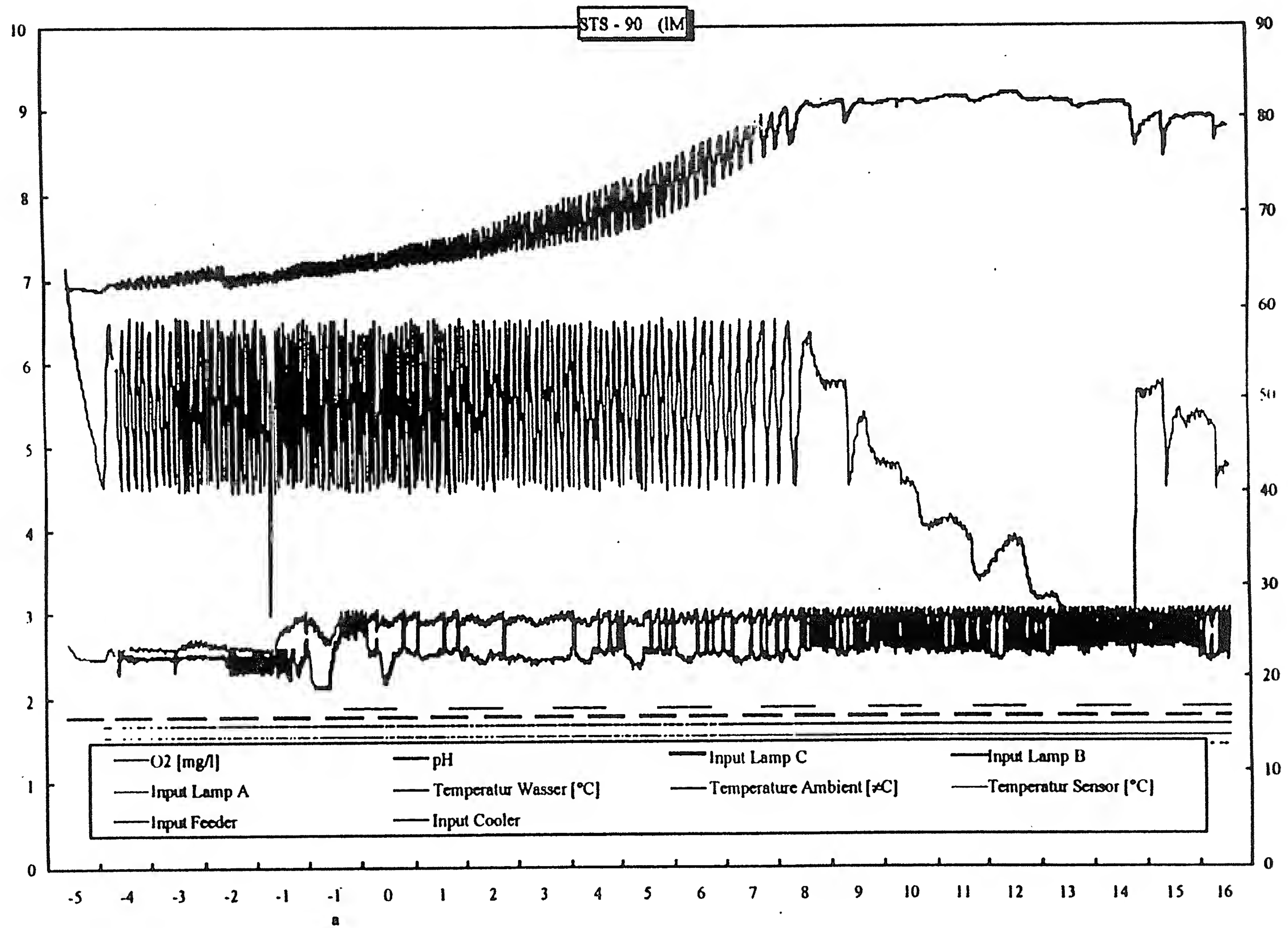
C. demersum		
	L-5	L+16
Weight (g)	49,8	115,5
Biomass Incr. (%)		231,8
Algae (g)	nd	very few

X. helleri (adult)				
	L-7		L+16	
	(g)	Days after Parturition	(g)	Days after Parturition

Female #1	1,48	L-18 to L-8	1,43	order of females
Female #2	1,59	L-18 to L-8	1,64	after retrieval
Female #3	1,22	L-18 to L-8	-	according weight
Female #4	1,71	L-18 to L-8	-	-
Total Weight	6,00		3,07	-
Avg. Weight	1,50		1,54	-
StDev.	0,21		0,14	-

X. helleri (juvenile)		
Born L- 9 to L-7		
	L-3	L+16
Avg. Number (Neo.Tank)	200	48
Survival Rate (%)		24
Avg. Weight (mg)	15,37	16,86
StDev (mg)	1,78	2,94
Avg. Number (Filter)	25	11
Survival Rate (%)		44
Avg. Weight (mg)	15,37	13,10
StDev (mg)	1,78	2,81

Aliens	Number
Planaria	1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O2 [mg/l]
pH
Input Lamp C
Input Lamp B
Input Lamp A
Temperatur Wasser [°C]
Temperature Ambient [≠C]
Temperatur Sensor [°C]
Input Feeder
Input Cooler
a

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 2002

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
Neurolab
Final Report for the Ames Research Center Payload

5. FUNDING NUMBERS
UPN 121-40

6. AUTHOR(S)
A. Christopher Maese* and Louis M. Ostrach,** Editors

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
*Ames Research Center, Moffett Field, CA 94035-1000 and
**NASA Headquarters, Washington, D.C. 20546-0001
--

8. PERFORMING ORGANIZATION REPORT NUMBER
A-0208939

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA/TM–2002-211841

11. SUPPLEMENTARY NOTES
Point of Contact: Christopher Maese, Ames Research Center, MS 240A, Moffett Field, CA 94035-1000
(650) 604-6633

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified — Unlimited
Subject Category 51 Distribution: Nonstandard
Availability: NASA CASI (301) 621-0390

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Neurolab, the final Spacelab mission, launched on STS-90 on April 17, 1998, was dedicated to studying the nervous system. NASA cooperated with domestic and international partners to conduct the mission. Ames Research Center's payload included 15 experiments designed to study the adaptation and development of the nervous system in microgravity. The payload had the largest number of Principal and Co-Investigators, largest complement of habitats and experiment unique equipment flown to date, and most diverse distribution of live specimens ever undertaken by ARC, including rodents, toadfish, swordtail fish, water snails, hornweed, and crickets. To facilitate tissue sharing and optimization of science objectives, investigators were grouped into four science discipline teams: Neuronal Plasticity, Mammalian Development, Aquatic, and Neurobiology. Several payload development challenges were experienced and required an extraordinary effort by all involved, to meet the launch schedule. With respect to hardware and the total amount of recovered science, Neurolab was regarded as an overall success. However, a high mortality rate in one rodent group and several hardware anomalies occurred inflight that warranted postflight investigations. Hardware, science, and operations lessons were learned that should be taken into consideration by payload teams developing payloads for future Shuttle Missions and the International Space Station.

14. SUBJECT TERMS
Neurolab, Life Sciences, Neuroscience, Spacelab, STS-90

15. NUMBER OF PAGES
171

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102